METAL PROGRESS

MAY 1934

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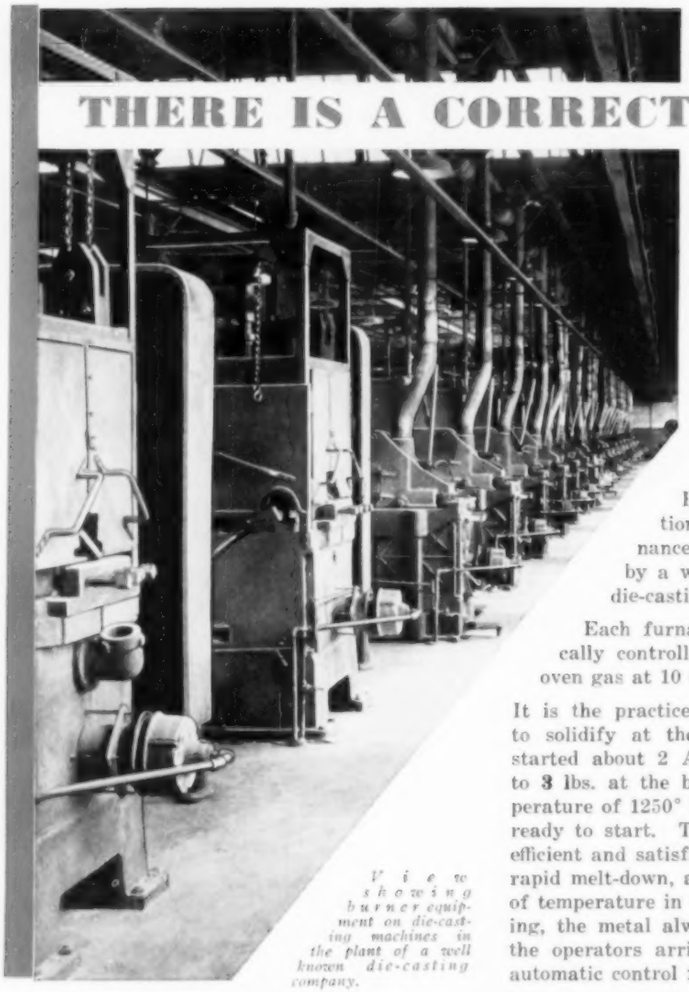
Because no one type of burner can handle all applications, SC burners are built in 46 different types and more than 400 different sizes. A very wide range of burner equipment is, therefore, available for whatever application you may require. The correct size and type of burners for your particular applications are assured.



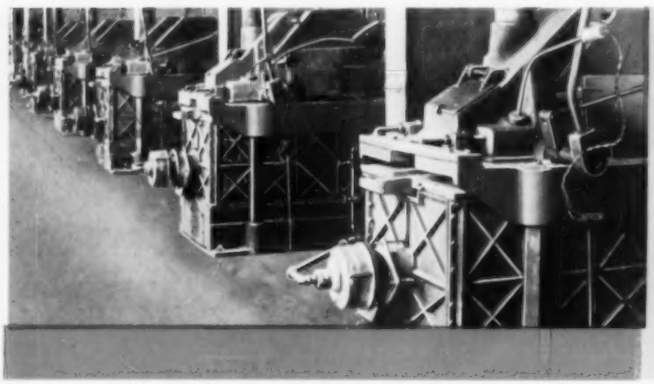
View showing burner equipment on die-casting machines in the plant of a well known die-casting company.

Production increased 15 to 18%, less fuel consumption, improved quality of metal, and lower maintenance costs -- these were some of the results secured by a well known Die Casting Company in converting its die-casting department from oil-firing to gas fuel.

Each furnace is fired by one Surface Combustion automatically controlled two-stage high pressure burner utilizing coke-oven gas at 10 to 15 lbs. pressure.

It is the practice in this department to permit metal in the pots to solidify at the end of the day's operation. Melting down is started about 2 A.M. in the morning with a gas pressure of 2½ to 3 lbs. at the burner. The metal gradually comes up to a temperature of 1250° F. and is held at that point until the operators are ready to start. This long melt-down time proved to be much more efficient and satisfactory than the previous practice on oil, of a more rapid melt-down, as it consumed less fuel and permitted no over-run of temperature in the metal. Time is saved in the start at the morning, the metal always being at proper operating temperature when the operators arrive, as well as in actual production through the automatic control features.

The life of the pots has been increased from an average of 11 weeks to an average of 16 weeks. The rejects caused by metal being at improper temperature have been practically eliminated.



Another view of SC Automatic Proportioning Burners in the same plant. These burners are effecting economies described here.

OPERATING DATA

Time of operation	8 hrs. 55 min.
Total production	1787 lbs.
Total gas consumption (during operation only)	4599 cu. ft.
Hot metal charged at 1200° F.	1556 lbs.
Cold metal charged	251 lbs.
Total gas (for melt-down and operation)	6362 cu. ft.

Surface Combustion Corporation

TOLEDO, OHIO

Sales and Engineering Service in Principal Cities

Also makers of.. ATMOSPHERE FURNACES... HARDENING, DRAWING, NORMALIZING ANNEALING FURNACES... FOR CONTINUOUS OR BATCH OPERATION

May, 1934
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Ernest E. Thum, Editor

Metal Progress

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All men who knew Dr. Walter Rosenhain, either personally or through his writings, felt a shock on learning of his untimely death. In his 23 years as superintendent of the metallurgical department of the National Physical Laboratory he became foremost in the new science of Physical Metallurgy. He received many honors from his countrymen. He toured America and lectured at several universities shortly after the War. He wrote occasional and vivacious letters to METAL PROGRESS. One of the world's leaders in scientific technology has passed.

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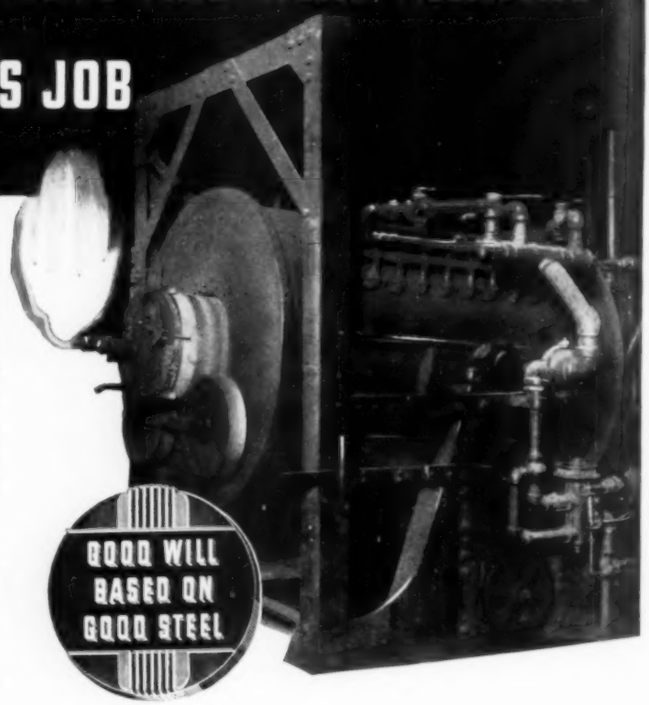

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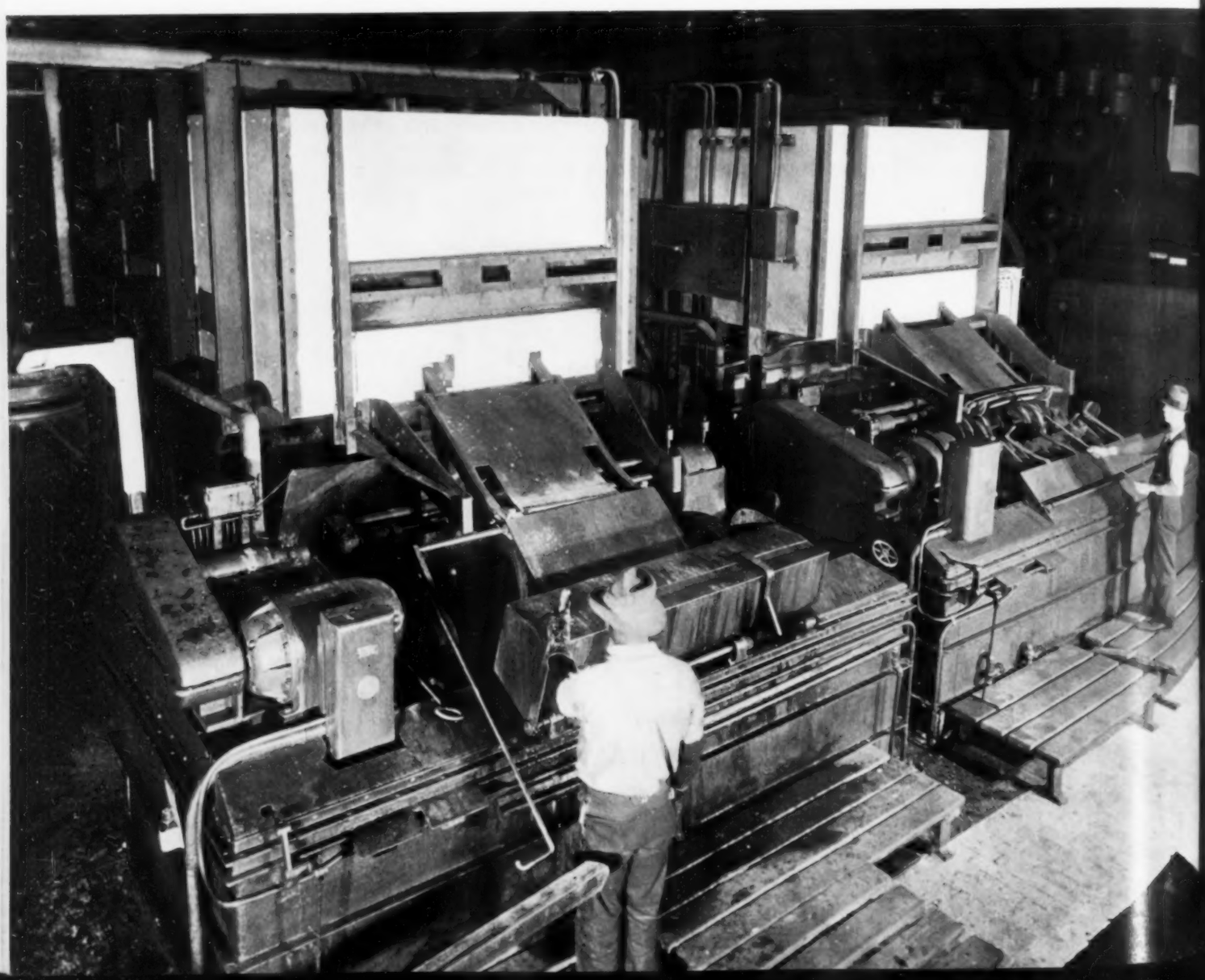
Faster forging at Ford's Rouge plant



THREE important changes have lately been made in the forging operations at Ford Motor Co.'s Rouge plant. Perhaps it would be better to say that important *trends* in practice have made noteworthy progress within the last 12 months, as follows: (*a*) Automatic feeding of upsetters, (*b*) simplification of work on front axles, and (*c*) trend toward gas heat. Each will now be briefly described.

High Speed Forging

Blanks for transmission gears have been made at Rouge plant, as commonly elsewhere, by upsetting a relatively small bar in four successive blows in as many dies. Usual practice is for the operator to transfer the bar, heated on one end, from die to die in the upsetter until the last operation cuts off the final attachment to the bar, whereupon the cycle of operations is repeated until the hot end of the bar is used up. Speed of production is therefore limited by the agility of the workman (who must go through a fixed series of transfers, time after time) and at best will equal about 120 pieces an hour for, say 3-in. blanks. Thought and skill have been lavished on the die design, so that the final desired shape may be approached by correct degrees, and flow lines ("fiber") in a sectioned and etched forging show no sharp corners or folds.

While such a standardized upsetting operation appears to be very efficient, and actually is very efficient as compared to a similar job made on a drop hammer, it obviously could be speeded up either by reducing the number of blows necessary to change the bar into a gear blank, or by devising a feeding machine faster and more precise than the human operator. Both means have been studied by engineers at the Ford plant, and at least one perfected example of each is now in steady operation on appropriate parts.

Upsetting by One Stroke — If advantage is to be taken of a lesser number of blows, it would be well to go all the way and do the job on one die. To make this possible one must start with as large a bar as can be used and still have the necessary degree of upset for a proper fiber or metallurgical structure. Furthermore, the forming die must be a closed one, made in one piece, in order to hold up to the excessive pressure and to maintain proper size — something a split die could not be expected to do. This in turn restricts the work to such shapes as may be designed or redesigned to have no undercut or channeled portions which would prevent them from being knocked out of a closed die. Lastly, the work must be done dry, as any coolant will likely cause steam pockets on the finished part where a drop of water has been caught between die and work.

The above statements outline in a very few words the principles upon which the newly devised equipment for gear blanks is operating. Former practice made a $2\frac{5}{8}$-in. gear blank from a $1\frac{7}{16}$-in. rod in a four-stroke upsetter. Present practice makes this same $2\frac{5}{8}$-in. gear blank from a 2-in. rod in a single stroke. Perhaps it is more accurate to say it is a two-stroke operation, as the first movement of the dies cuts an accurate slug from the end of a hot bar held in place by the operator, and before the machine closes this slug is transferred automatically sideways and held immediately in front of the upsetting die. The punch, coming forward, catches it in the very center and forces it into the forming die, expanding it and upsetting it completely as the leverage passes over dead center. Knockout pins, working through the center of both die and punch, eject the gear blank as soon as the punch draws back. Structure of the forgings is excellent, as shown in the etched sections reproduced on page 18.

In this operation, the role of the operator merely consists in thrusting the hot, de-

Hot Axles Slide Out of Upper Hearth, Down Incline and Into Quenching Machine. This grips the piece tightly and, rolling over, submerges it in caustic solution. Cold axle is automatically discharged at rear edge of tank and starts back through lower hearth for draw

scaled bar endwise into an opening until it strikes against a stop, and doing this six or eight times in succession until all the hot metal is used up. Then comes a delay while he passes the cool stub back to the furnace and gets a second hot bar. Periodic delay is necessary, however, to prevent overheating the punch and die, which, as noted above, must run dry, without coolant. The die steel is the standard hot-work steel used on a great many other forging operations. It contains, 0.60 to 0.75% carbon, 3.5% chromium, and is heat treated to 387 to 418 Brinell hardness.

Macrostructure of Gear Blanks Made by Single Blow Upset Is Satisfactory. Full size. Steel has 0.32% carbon, 1.0% chromium

This operation, of making 2⅝-in. gear blanks of 0.32% carbon, 1.0% chromium steel, is done in a special National upsetter, 4-in. capacity, at the rate of about 500 per hr. Two men are required, one to handle stock and blanks, and the other to feed the machine. Unconsumed bar ends are only 2 in. long.

Comparative figures for a 4-stroke operation are 150 blanks per machine-hour or 75 per man-hour. Unconsumed scrap pieces are 8 in. long — 10% of the raw stock.

Automatic Feeder

Automatic handling on an upsetter is now being performed on rear axles, a $1\frac{5}{32}$-in. rod, 37 in. long, on which a blank for $3\frac{1}{16}$-in. diameter bevel pinion is upset at one end. This set-up includes a special heating furnace and the complete unit is designed to be operated by a single mechanic plus two laborers required to load the bar stock into the furnace and clear away the completed axles.

The furnace itself is quite interesting. It is set on a low balcony at one side of the upsetter, so that hot bars may discharge by gravity to the feeder. It is rectangular in shape, but its floor is cut through by a slot, hairpin in plan, and an inner longitudinal wall inside divides the heating chamber into a U shape. Two gas burners are placed in the end walls on the cold side, and eight more in the side wall of the hot, or discharge side.

An appropriate structural frame carries a conveyor loop directly below the slot in the hearth, and each link on the chain carries a spring clip for holding a bar. This bar then stands vertically, with one end up through the slot and into the hot interior. As it is carried slowly to one end of the furnace, then around and back along the other side, this end gradually approaches the proper forging heat, 2250° F. When finally it reaches the end of its travel, the spring clip grasping the cold end is automatically opened, and the bar drops down a curving chute, and is delivered to the forging machine with hot end pointed in the right direction.

As the view at the right shows, a short conveyor has been placed between furnace chute and upsetter, which conveyor is synchronized with the forging operation, thus correcting any irregularity in delivery of hot bars. Furthermore, at one station in its passage the bar is vigorously hammered by an opposing pair of air hammers, and furnace scale is thus removed. A few seconds later the bar is pushed forward into the jaws of the automatic upsetter.

As far as the upsetting machine proper is concerned, it is a 4-in. special of National design, quite massive. It carries four dies in a row, one directly below another, uniformly spaced, center to center. The first operation upsets the bar end into a tulip-bud shape, the second into a stocky truncated cone, the third flattens this cone out into a gear blank, while the fourth restrikes the blank after a 90° turn. This is exactly the same as a hand-operated routine. A good volume of coolant deluges the dies and punches (which is permissible since there is an opportunity for restriking, and any gas pockets can thereby be eliminated). This

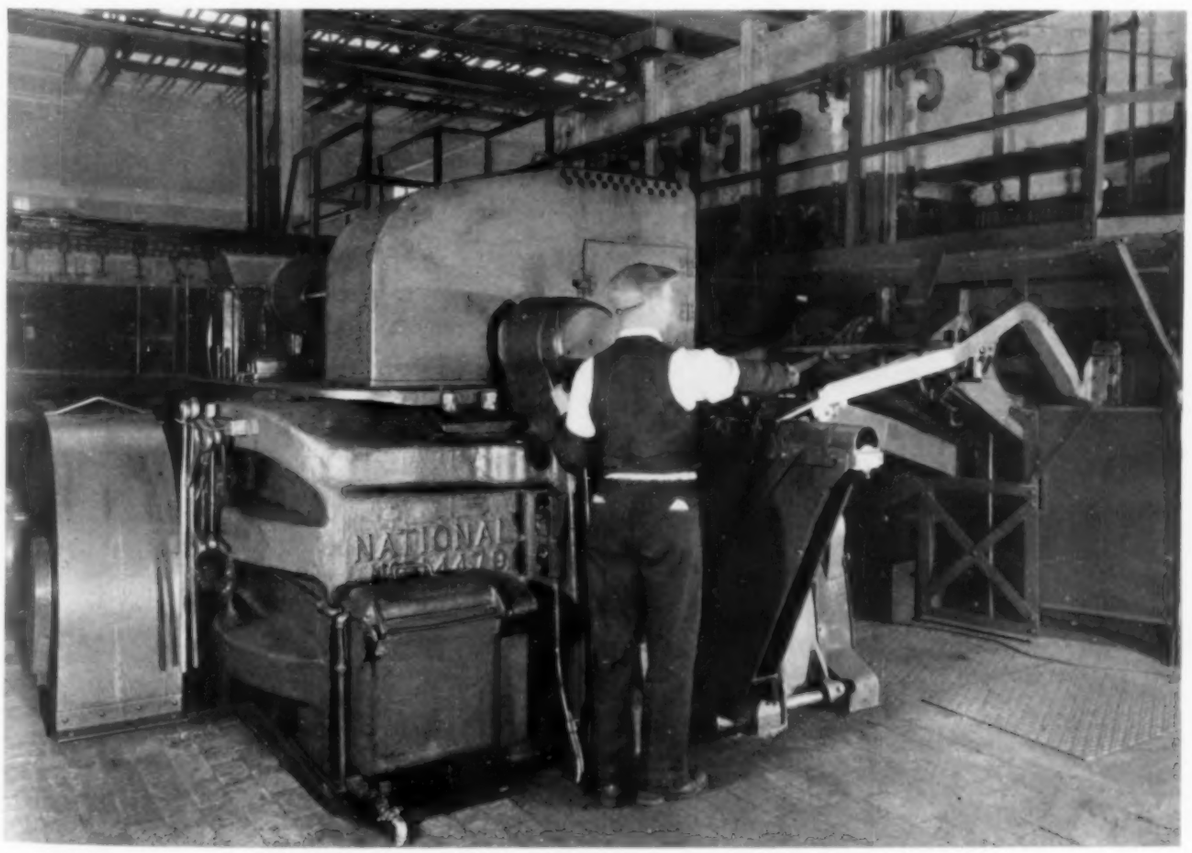
also means that forging action can be continuous without overheating the dies.

The unique device here is an automatic transfer which carries bars from die to die in such a way that each station is refilled as fast as emptied. Thus the upsetting machine produces one complete axle at every stroke, rather than one every four strokes; further, the rhythm is not interrupted for a new bar to arrive; one is delivered in time to be in the first upset at every closure of the dies.

This automatic transferring device is essentially a pair of blocks with grooves cut into their abutting surfaces so that when they close four holes are formed, slightly less in diameter than the axle shaft and so spaced that they grip shafts protruding from each of the dies in the upsetter. The blocks are attached to cam-operated levers so they move apart or together, and up and down in the proper sequence as follows:

Suppose that the dies in the upsetter have closed and the punches are operating. At this time the feeder blocks or jaws move apart and up the exact distance center to center of dies. Then they close. This occurs before the upsetter dies reopen, so the feeder jaws have a firm grip on axles in dies No. 1, 2 and 3 (counting from the top) as well as a heated bar which has previously been delivered to top position "zero". When the upsetter dies open, the restruck axle in the lowest die No. 4 drops out of the machine, finished, onto an elevating conveyor. Four bars are now held firmly by the feeder, which then moves downward a distance equal to center-to-center of dies. As it arrives there a "stop" bar moves up and pushes each bar slightly into the upsetting machine in correct position to be gripped by the closing dies, and the cycle is completed. Each die is then filled, ready for its appropriate operation.

It should be mentioned that the grip on the bar in die No. 3 is not so tight that it cannot be turned 90° before restriking, by an ingenious



Rear Axles Are Heated on One End in Elevated Furnace and Fed One at a Time by Conveyor Into Massive Upsetter. An automatic feeder in front of operator transfers stock from die to die, in such a manner that all dies are working every time machine closes

rotating device which turns as the feeder moves downward.

This machine has hardly been in operation long enough to determine the maximum economical speed, but so far the best production in an 8-hr. day has been 5600 axles, or 700 per hr. One laborer is required to load cold bars into the conveyor at the furnace, another to remove finished axles, and a mechanic to supervise the machine. The old method of hand feeding a 4-die machine required one operator (and a helper to de-scale the bars and handle stock). The best production of such a team was 120 upset axles in an hour.

Forging Both Ends at Once

Simplification of work on front axles, the second item mentioned at the outset, has reduced the number of forging operations from seven in three machines to three in two large presses. Formerly, 23 men were needed to turn out 1000 axles a day, whereas now only six are required. One discouraging part of the old practice was the number of rejects (despite the rather large tolerance of ¼ in.), which could hardly be driven below 2%, due to the difference in shrinkage of the axles heated locally for the separate operations to somewhat variable distances and temperatures (despite the greatest care in this respect). Now that the complete job is done on one heat in two strokes of one machine, there is little opportunity for variation (when forging temperatures are under control) and rejects for out-of-size are practically zero.

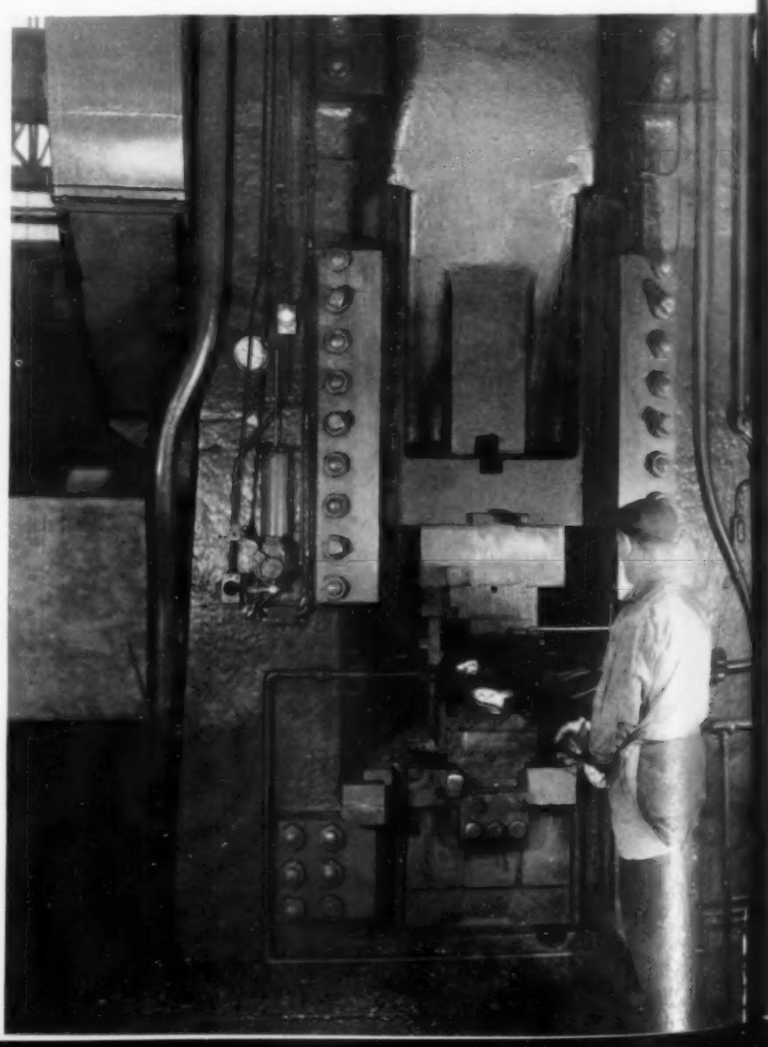
Old practice started with a straight bar of 0.37% carbon steel, 1x1¾x61 in. in size. It was heated and upset on each end in succession. Next it was heated and forged on either end to center of axle and the flash trimmed. Finally the center of the axle was heated and stretched to correct length.

New practice starts with a special bar of the same analysis, rolled to variable cross-section on grooved rolls by the steel supplier. This bar has a lump of metal at either end and the central portion has an I-bar cross-section. Thus, part of the work formerly done in the forge shop is now done in the rolling mill.

These bars are fed through a pusher furnace, so arranged that the center rides down a relatively cool passageway but the ends stick through slots into hot side-chambers, gas fired. Emerging, they are at 2150° F. at each end, where much work must be done, yet the central region is not yet glowing. Bars are skidded directly into a massive press (one is of National and another of Cleveland make) of 1800 tons capacity. Dies are 10½x14x60 in. in size.

The first stroke in the edger bends the bar (cool center included) into the long, sweeping curve required by the design. Next the bent axle is tipped over on its side into the forming die, the scale is blown off, and a single squeeze brings the ends to shape. All that remains is for a second press to trim off the flash, and the axle is ready for heat treatment.

Instead of Upsetting and Forging Front Axles One End at a Time, the New Plan Uses a Rolled Bar of Non-Uniform Section and Bends and Forges it in Two Strokes of a Massive Press



With a standard heat and correct dies a constant shrinkage on cooling can be depended upon, and practically none of the axles are rejected as being beyond dimensional tolerance, restricted to $\frac{1}{16}$ in. on the length.

Advanced Furnace Practice

There are about 160 furnaces serving the forge and upsetting machines at the Rouge plant, many of them of the conventional slot type, ranging around 10x4x3 ft. in outside dimension and set on legs of appropriate length. Perhaps their only feature worthy of remark is the practice of covering the hearth bricks with a 3-in. bed of crushed dolomite. This absorbs the oxide and "slag" from the heated bars, may be readily renewed at alternate week-ends, and protects the permanent brick work quite effectively and economically.

Included in the number are many special furnaces for individual parts, but these utilize some style of protected conveyor or external pusher for delivering a constant supply of hot metal, usually heated only in those regions where forging is to be done. Possible variations of this general idea are, of course, almost infinite. Two specific examples have been sufficiently described above, one furnace for heating rear axle shafts on one end and another for heating front axles on both ends.

Source of Heat — A great deal of experience has also been acquired with heat from three sources — oil, gas, and electricity. This may be briefly summarized by saying that oil, while the cheapest under most conditions when figured back to cost per pound of steel heated to forging temperature, requires the most expert attention. A battery of oil-fired furnaces must be constantly watched by a "heat man," and even then the percentage of burned forgings due to accidental interruptions at the hammers is bound to go up. Furthermore, oil burners are dirtier, and every attempt is made to keep even the forge shops clean at all of Mr. Ford's properties.

Electric heat, on the other hand, is usually the most expensive, and unless special gas atmospheres are maintained in electrically heated furnaces, the scale, though thin, is hard and adherent. Electricity's great advantage is cleanliness and ease of control, and for the former reason especially, it is favored wherever furnaces must be placed in direct line of machine work or assembly.

The present trend, therefore, in heating operations at the Rouge plant (for heat treatment as well as forging) is to use coke oven gas up to the limit of available supply. Its cost is but slightly greater than oil, figured on the basis of one pound of steel to forging temperature. To provide against shortage, however, most of the forging furnaces are piped with dual lines — one for gas, one for oil — and arrangements made for ready replacement of burners.

Gas burners are made to Ford design. Most of them contain proportional mixers of the venturi type for gas and air. Gas is furnished at 15 lb. pressure and the inspirator is set to draw in whatever volume of air is desired to get a "lazy flame," with excess of gas, automatically maintained at the correct proportion regardless of the amount of fuel being burned.

Pyrometric Control

Many of the furnaces are operated with a steady through-put of work, so pyrometric control is found to be somewhat superfluous on about two-thirds of them. Control, when installed, usually consists of a motor-operated valve in the gas supply line, operated by electrical relays or boosters from limit contacts set on a thermocouple recorder.

A thorough trial was given of so-called diffusion combustion above a blanket of raw gas, thus reducing scale on the hot bars to the vanishing point. This is an important factor when forgings must be made to small dimensional tolerances, or when they are made with a single operation. On other work there is, of course, a saving of the weight of steel converted to scale, but this is a minor matter. In the manufacture of "rough" forgings, therefore, it was judged that scale-free heating was of insufficient economic advantage to warrant reconstructing the heating furnaces serving hammers and presses. The scale produced in a "soft" flame from an ordinary gas burner is completely removed by the first hammer blow, and for much forging stock this also removes a slightly decarburized skin and minor surface irregularities.

Practical procedure for gamma-ray testing

by Gilbert E. Doan
Asso. Prof. of Physical Metallurgy
Lehigh University

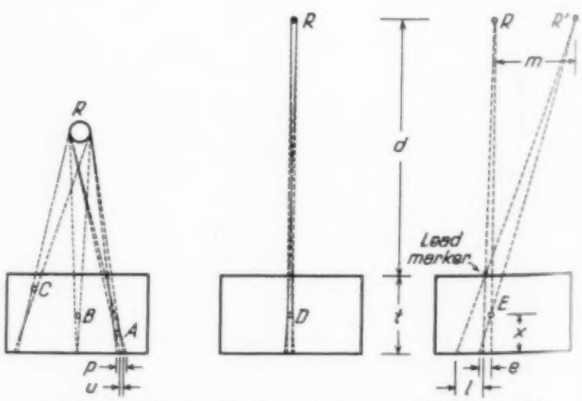
WHILE X-rays have been used with gratifying success for the testing of solid objects for internal flaws in the art of radiography, they have certain shortcomings. The practical limit is 4 in. of steel. In the second place, the equipment is bulky and not very portable, being practically anchored to a source of high voltage electricity.

Gamma rays from radium, its emanation, or from mesothorium, avoid these limitations. A capsule less than ¼ in. diameter contains enough radioactive substance for examining any commercial object. It can be transported anywhere; no complicated machinery is required and hence no expert electrician is necessary.

Pioneering experiments in the use of gamma rays for radiography were carried out in 1929 by Dr. Mehl, Dr. Barrett, and the writer, and announced at the 1930 convention of the American Society for Steel Treating. They established the entire practicability of the method for both thin and thick sections of metal, and since then a number of applications have been made to routine testing, both here and abroad. The present article is a condensed account of the practical procedure, written after having responded to continued requests for engineering and economic data received from men in industry. Assistance of Dr. Mehl, Dr. Barrett, and Dr. Canfield of the U.S. Naval Research Laboratory is gratefully acknowledged.

The method is extremely simple. The pieces to be studied are mounted some distance from the radioactive substance, facing it from any angle (for the radiation spreads out in all directions with equal intensity). A photographic film with intensifying screens, in a light-tight envelope, is placed behind that portion of each object to be studied. Some of the rays are scattered by the solid metal; the remainder pass through and register on the film in quantity and effect proportional to the thickness of the interposed material. Missing metal, as in a flaw, is registered as a shadow on the film.

Arrangement and Equipment — Recommended films are Eastman "Diaphax" or "super-



Sketch Showing How Size and Location of Radiant Source Affect Sharpness of Images. Depth of flaw is located by double exposure

speed dupli-tized X-ray" films. To shorten the exposure German intensifying screens known as "Supra-Sinegran" or the *extra thick* calcium tungstate screens of American manufacture are best. Two screens should be used for each film, one in front, one behind. Lead foil may be used instead of these screens if a longer exposure at an appropriately greater time is permissible.

Exposure Times in Hours Equal Intensity, Initially

Radium	Emanation
1	1.0
5	5.1
10	10.4
15	15.9
20	21.6
25	27.7
30	34.0
35	40.6
40	47.6

One of the first questions to be decided in planning a test is the size of the smallest flaw which it is desired to detect. If minute flaws, such as those in welds, are searched for, the distance from source to film should be as great and the radioactive source as small in size as possible.

The first sketch shows, at the left, how a large source of rays placed close to the test object blurs the outlines of the image of a flaw A. A spot u on the plate corresponds to the umbra of the earth's shadow, while the annular region p of lesser contrast corresponds to the penumbra. If the flaw were located further from the plate, as at B, it would be barely distinguishable and if at C would probably be missed. A successful method of detecting all flaws, regardless of position, has recently been developed here at Lehigh University and will soon be published.

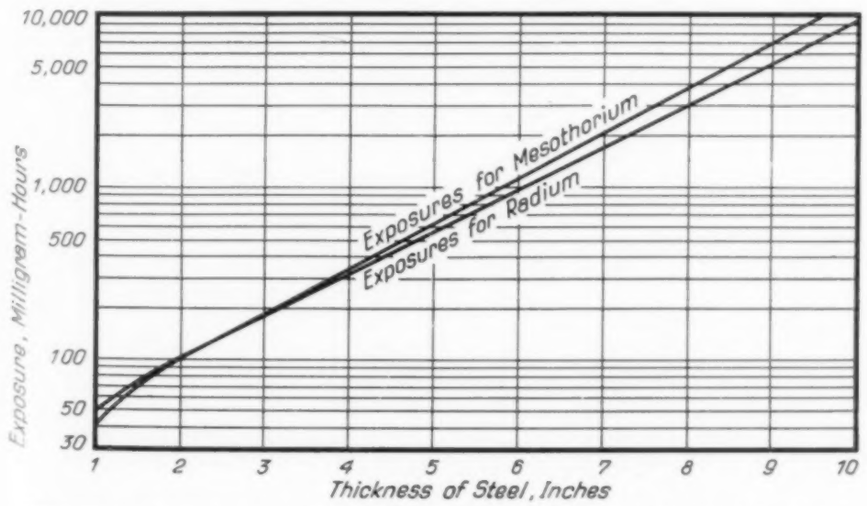
It is obvious that as the source of rays is further removed from the object, the rays reaching the film become more nearly parallel. A sharper definition of the flaw is then obtained, for the size of the umbra is increased and the penumbra is diminished. A further improvement is obtained when the radiant source R is small in size, as shown in the center sketch. If flaw B were, say, three times as large as shown, it would be detected (although with a hazy outline) even with large radiant source close to the object. But if it were only one-tenth as large, it might be necessary to use a larger distance d and a small source of radiation.

Images are, of course, sharper as they are located near the film. This enables one to estimate the approximate distance of an internal flaw below the surface. A better location can be made by a double exposure, moving the radiant source parallel to the film a measured distance m to a new position. If d is great, as compared to t, then an approximate solution for x is made by similar triangles, thus:

$$x : e = d : m$$

It may be simpler to place a lead marker on the object near the flaw; we then have the approximate proportion $x : t = e : l$.

Since the time of exposure increases as the square of the distance, d, the choice of distance will of course be influenced by the time consideration. If, on the other hand, relatively gross flaws are sought, this distance may be made very short. For instance, a hole 1½ in. deep and 3 in. diameter in a synthetic block of steel 10 in. thick will be adequately revealed when a distance, source to film, of 12 in. and a relatively large source of rays, such as six bulbs of emanation, are used.



Exposures for Steel, According to Berthold and Riehl, for Single Agfa X-Ray Film With Two Supra Sinegran Screens, 12 In. Distant From Radiant Source

Once the distance from source to film has been chosen (and the size of the source, as well as the quality of the films and screens), the time of exposure in milligram-hours for steel sections is read from the graphs at the bottom of the preceding page.

For example, 4 in. of steel requires about 300 milligram-hours. Whether a source of 300 millicuries intensity is used for 1 hr. or 100 millicuries for 3 hr., or any other combination is of course immaterial from this standpoint. If two films are exposed and viewed superimposed, the time of exposure is diminished about 40%, but in routine work on moderate thicknesses, the films cost far more than the radiation (as will be demonstrated later).

For distances other than 12 in. multiply the exposure indicated on the chart by the square of the distance measured in inches divided by 144. For materials other than iron and steel the computed exposure time for steel t_s must be further corrected for density of the material D_m by using the proportion

$$t_m : t_s = D_m : 7.8$$

When radium emanation is used, a correction for its decrease in intensity during the exposure may be necessary. The table at top of page 23 gives the exposure necessary for radium emanation to equal the effect of a radium source of the same initial intensities. The rates of decay of radium and mesothorium are so low that their decay during exposure may be neglected.

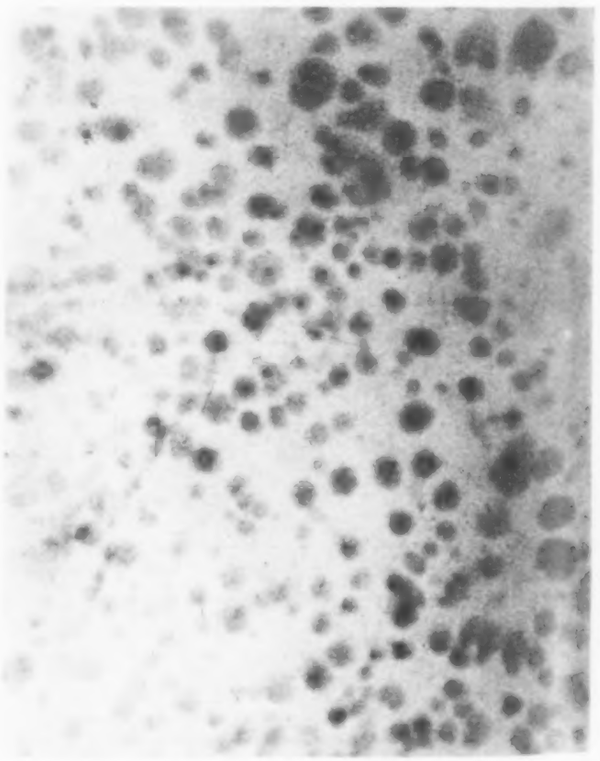
The original experiments with gamma rays showed a sensitivity of 2% without reaching the limit — that is, a flaw could be unmistakably registered upon the film whose thickness is 2% of the total thickness of the test object (both measured in a direction parallel to the rays). Later experiments by Norton and Ziegler have shown a sensitivity limit of 1.3% for pieces from 2 to 7 in. thick.

The shading of thinner portions from overexposure (by plastering them with lead chips or iron filings in a binding matrix, as is done in X-ray radiography) is rarely necessary with gamma rays. As a matter of fact, gamma rays permit a very wide latitude of thickness in the same object, without requiring these paste screens or two exposures — one for the thicker parts and another for the thinner parts. The greater penetration of gamma rays is responsible. While the contrast between flaw and homogeneous metal is sharper with X-rays, every defect visible in the X-ray radiograph is visible in the gamma-ray test. Precautions against "back scattering," which are nearly always necessary with X-rays, also are not usually required with gamma rays.

Accompanying halftones illustrate one practical application of gamma-ray radiography in testing a massive casting. The radiograph shows excessive porosity, as does the photograph made after the surface has been chipped away. These defects were found to be due to the fact that a repair had been made to the mold at this location, and the latter had not been properly dried before the metal was poured. These views are presented through the courtesy of L. W. Chubb and N. L. Mochel of the Westinghouse Co.

Reading the Films

The most satisfactory method of reading the films is before the viewing cabinet, such as used in hospitals. Additional certainty in in-



Part of Gamma-Ray Radiograph of Heavy Casting. Surface of this portion was cut away, revealing conditions shown at right, due to a moist patch in the mold

terpreting a faint marking on a film is obtained by exposing *two* films together in a single envelope with suitable intensification screens on both sides of each film. There is less doubt whether a faint marking may be due to a defect in the film. The exposure time to produce a visible blackening on two films, if viewed superimposed, is shorter, and the saving in time may be worth the cost of the extra film and its development, when examining thick metal.

Another method of viewing a film is to lay it upon a sheet of white paper. The light passes through the film once on its downward course and again after it is reflected from the paper to the eye, thus accentuating the contrast. Less dense films than those used in the viewing cabinet are best suited for this method, but the double film is of relatively little advantage under these conditions.

No exposure of the operator to personal injury is necessary. When removing the radium from one place to another, forceps or tongs a foot or two long, together with the length of the extended arm, will give adequate protection for the short time involved in transfer. At other times the best precaution is to stay 20 ft. or more away from it. When the source is to be stored where persons pass near it, a housing of lead as thick as 6 in. is adequate protection. For transportation a thinner lead wall may be used and a suitable distance maintained.

To test the degree of personal exposure, the operator may carry a small bit of unexposed film in a light-tight envelope in his pocket. If the film does not blacken in two weeks, the exposure of the person has been negligible. Standards of safety set by a committee of the League of Nations have been quoted by V. E. Pullin in "Radium in Engineering Practice" read before the Institution of Mechanical Engineers, 1933.

Economic Utilization

It will always be most expedient to surround the radiant source as completely as possible with test objects and thus to use as much of the broadcasted rays emerging from it as possible. Obviously, a number of concentric

great circles of objects could be exposed at the same time with very sharp definition and with correspondingly short time of exposure, when calculated per object exposed.

In order to utilize the time to best advantage, some appropriate frames can be constructed and while one group of objects is being exposed, the second frame can be supplied with test objects. The radioactive source may then be transferred as soon as exposure of the first frame is completed.

In routine examination of objects the source could thus be usefully employed nearly 24 hr. a day, the frames for night exposure being so designed to give a good film after 16 hr.

Cost — The cost of the radiant energy per specimen tested will depend in large degree (under any given set of conditions — such as kind of film and screens) upon the size of the flaws to be detected and the size of the radiating source, the thickness and density of the test objects, the degree to which the source may be entirely surrounded by test objects, and the continuity with which the source is employed. To this cost for radiation must be added the labor in assembling the objects, the films and their development, and the observer's time required for examination and interpretation of the films.

Assume that one gram of radium is owned or bought outright for $60,000. Assume use of 24 hr. a day for 250 days in the year; that is, 6000 hr. use per year. The interest on the investment at 6% will be $3600, insurance on the radium $1800, a total of $5400 or 90¢ an hr. Wages of observer are $10 for an 8-hr. day and of laborer $3.50. This amounts to $2.60 per hr. for radium and labor.

Shape Factor

If minute flaws are to be detected a distance of 18 in., source to film, might be desirable. The next question is "How many objects can be grouped about the source at this distance at one time?" Here enters a "shape factor" which will determine how closely the objects may be packed on the surface of the imaginary sphere 36 in. diameter. If the entire surface could be filled with test objects, the volume of steel 3 in. thick that could be tested at one time would be the volume of a sphere 36 in. diameter minus the volume of the inner space 30 in. diameter, or 10,300 cu.in. On the average, perhaps one-half the theoretical area could be used (shape factor = 0.5), so the amount of steel tested simultaneously would equal, say, 5000 cu.in. or 1400 lb. The time of exposure for a gram of radium (from the curve on page 23) is 45 min.— in round numbers, 1 test per hr. at $2.60 for radium and labor, or a cost of testing 3-in. steel of $3.70 per ton or about 0.2¢ per lb. The cost of films and chemicals at 0.5¢ per sq.in. of film would be an entirely simple calculation and the same as for X-rays, and for this section of metal comes to 1¢ per lb.

Obviously, the exposure cost increases and the film cost decreases, per pound tested, as the thickness of the material increases. The shape factor may perhaps be as little as 0.1, but it is necessary to assume some basis for calculation and it seems most convenient to assume 0.5 as an ideal case and then modify it for each departure therefrom.

It is evident that the film costs, which are the same both in X-ray and in gamma-ray testing, constitute the major part of the total cost in these examples. However, if testing is done only occasionally, the overhead expense will make the cost of radiation *per object* higher than the film cost.

Costs of the magnitude of 1.2¢ per lb. for testing would constitute a very slight increase in the basic production costs of important metal objects. Where the risk involved from defects is small, this increase in cost would not be justified, but for others, such as high pressure valves, it would enhance their value enormously.

In summary, it may be stated that if only one exposure is to be made at a time, it is cheaper to use X-rays when the thickness of steel is below 4 in., but that if several objects are exposed at one time the gamma-ray method may be cheaper not only for 4-in. sections but also for very much thinner sections, depending upon the number of objects exposed at one time. Especially if the testing is carefully scheduled and is carried out in a routine manner, as in commercial production programs, the gamma-ray method offers certain distinct advantages. The cost of films and development is the same in both methods. For occasional testing, radium may be rented from a hospital.

High strength alloy castings for cranks

by A. F. Moyer
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ENGINEERS of all sorts will accept the statement that modern structural steel, even of the mild low carbon variety, is far superior for load-carrying members to the wrought iron bars of two or three generations ago; perhaps the steel shapes, as rolled, are 40% stronger than their predecessors. Unfortunately, it is not so generally realized that improved and more rigidly controlled foundry methods, now quite common, are uniformly producing gray iron castings that compare even more favorably with similar products of our fathers' and grandfathers' time. Many engineering handbooks still in current circulation give the tensile strength of gray cast iron as 15,000 to 20,000 lb. per sq.in. Good foundry practice consistently adds 60% to these values, and by the addition of alloying elements in relatively small amounts, the strength under properly controlled conditions can be doubled, if not trebled.

Designers, who base their work on a mathematical analysis of the stresses carried by the various machine parts or structural members, always have to reckon with a number called the factor of safety. This factor is selected according to experience and the judgment of the chief engineer. It must necessarily be taken large enough to allow for a number of uncertainties, including such variations in the material as are likely to occur in manufacture.

In this respect, cast iron has not, in the past, enjoyed a good reputation for uniformity, since it has been subject to many defects, such as porosity or shrinkage cavities, casting strains, cold shuts, blowholes, brittleness, and included dirt. By proper cooperation between designer and foundryman, some of these troubles can be and have been reduced. Studies in the foundry as to the design of the pattern and mold, methods of gating, control of foundry sands, are effective in removing many more of these damaging variables. Metallurgical control of the iron, such as the ingredients, melting temperature, degree of mixing, and the pouring temperature, also contribute to the uniformity of the castings.

Whenever a material is known to be dependably uniform, the designer is justified in reducing his factor of safety, which is to say that he places greater unit loads upon the material, and consequently makes a lighter, more economical, and a better machine. (A case in point is the general agreement among structural engineers that mild steel for bridges and buildings may safely be figured at 18,000 lb. per sq.in. in tension instead of the 16,000 lb. which formed the basis of all computations up to a few years ago.) For parts which carry a fluctuating load, his upper limit is the endurance limit of the metal, and he takes care that the

shape of the piece does not bring about stress concentration due to sudden changes in sections, such as notches, shoulders, or sharp fillets.

It has recently been shown that for pieces of similar shape, some materials are capable of being stressed more nearly up to the endurance limit (as determined by laboratory tests) than other materials, without danger of fatigue failure in the areas of stress concentration. This is related to the property called "damping capacity." Relatively inelastic materials, such as soft steel and cast iron, have a high rating in this respect as compared to hardened and tempered steels which have a high elastic limit, close to the ultimate strength. By the same property, soft steel and cast iron are less likely to transmit vibrations, or to respond in resonance to imposed vibratory forces.

While the trend in alloy steels is toward lower alloy content and cheaper elements, the gray iron foundryman is improving his castings by adding moderate amounts of nickel and chromium. He also is melting hot, with considerable steel scrap in the charge. Such castings are now competing with forged and heat treated machine parts.

These considerations — greater strength, higher uniformity, larger damping capacity — all lead the designer to place greater confidence in cast iron, as soon as he can have full assurance that quality is uniformly maintained. These advantages are in addition to the admittedly great advantage of producing intricate shapes with the greatest ease.

A striking example of the application of cast iron to a major stress member is in crankshafts for internal combustion engines. One analysis of iron employed for this purpose, as quoted by the editor in METAL PROGRESS for February, might almost be called a high carbon alloy cast steel, it is so low in carbon. Its strength compares favorably with rolled or forged mild steel, even if somewhat inferior to a heat treated "40-carbon" steel forging. To many people this application is most surprising, since it has always been maintained that crankshafts are subject to severe punishment, and therefore should be made of the toughest material, particularly since a failure during operation might ruin the engine.

If a thoughtful observer will but remember the changes that have gradually taken place in crankshaft design during the past 20 years, he will note that bearings for both piston rod and shaft have greatly increased in diameter, with consequent reduction in the actual stress within the materials. This increase in size, made to reduce wear in the bearings, has actually reduced the tension, compression and shearing stresses in a uniformly proportioned crankshaft to values where gray iron can be considered as a material from which to make them. This statement at least is true of uniformly high grade varieties of alloy gray cast iron containing properly applied steel scrap.

Aside from the reduced cost of the casting process as compared to the forging process, there are further advantages of cast iron for crankshafts as compared to steel, one of which is the bearing properties of the metal. It is well known that a cast iron bearing is very resistant to wear. This is true also of the harder, stronger, high test cast irons. The machinable hardness of the most suitable grades of cast iron is even greater than that of heat treated steel. Therefore, if the modern proportions of bearings are retained, their durability can be still further increased. In fact, the bearing properties of cast iron are good enough so that forged aluminum connecting rods can be run in direct contact without the usual bushings.

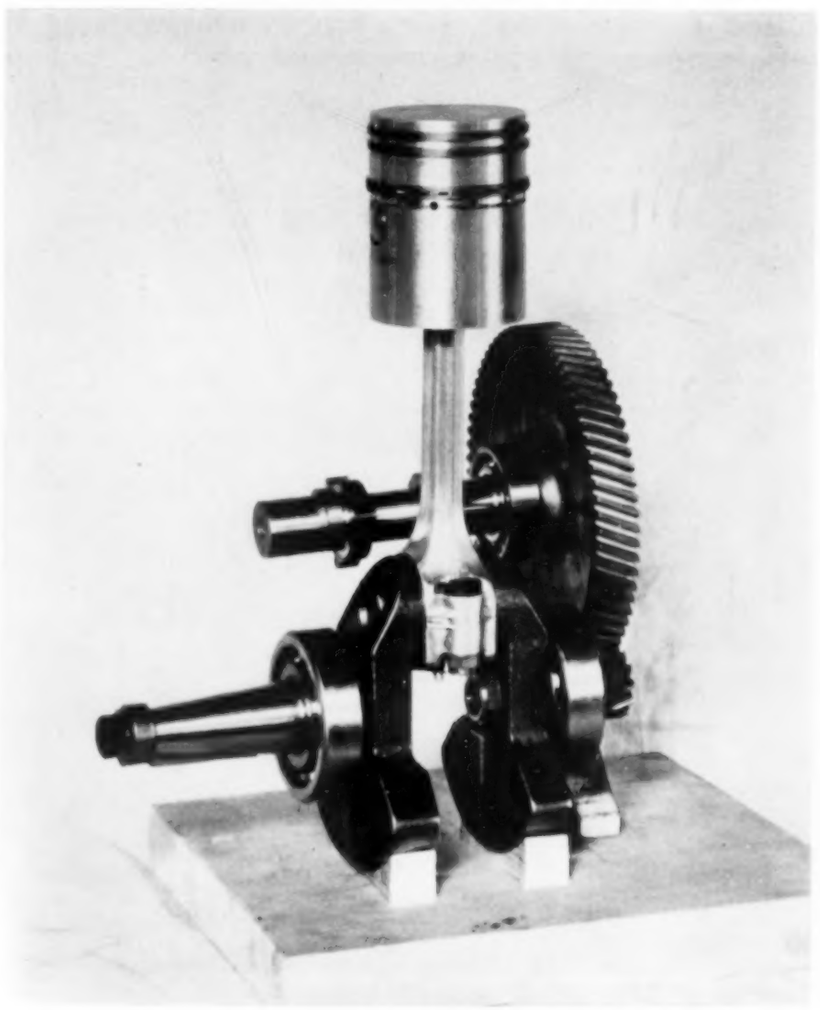
Modern designs of crankshafts are counterbalanced in some way. The problem of forging the counterbalance weights integrally with the shaft has been a difficult one. In some cases it has been economically impossible; surfaces would then be machined on the cheeks of crankshafts and counterbalance weights bolted on. The casting process permits one to form these weights readily in one piece with the shaft. Cored holes through the crankpins also reduce the counterweights. Lastly, with precise mold

ing methods, cast shafts can be produced with small dimensional variations, and are therefore economically handled in the process of accurately balancing.

If the principles of good design are applied, cast iron is a feasible material for most of the conventional types of multi-throw shafts for automotive engines — it being well known that the Ford Motor Co. now has cast crankshafts in production. The illustration herewith shows the working parts of a single cylinder engine with a cast iron crankshaft, made by the author's firm. This engine has a low expansion, heat treated aluminum alloy piston and a drop forged and heat treated aluminum alloy connecting rod. This rod is reamed to fit directly on the ground pin of the cast iron crankshaft without shims or babbitt. This bearing requires only constant level splash lubrication, employing a dipper formed on the rod. The helical timing gears, which normally transmit the entire horsepower of the engine, at 6 to 1 ratio, are cut from S.A.E. 3250 chrome-nickel steel, oil hardened and drawn.

The iron in the crankshaft is produced in a cupola, and contains 18% steel scrap. The analysis is: Total carbon 3.30 to 3.40%, silicon 1.70, manganese 0.60 to 0.80, phosphorus 0.20%. To this is added 2% nickel and 0.75% chromium. The hardness is Rockwell B-97 to 101.

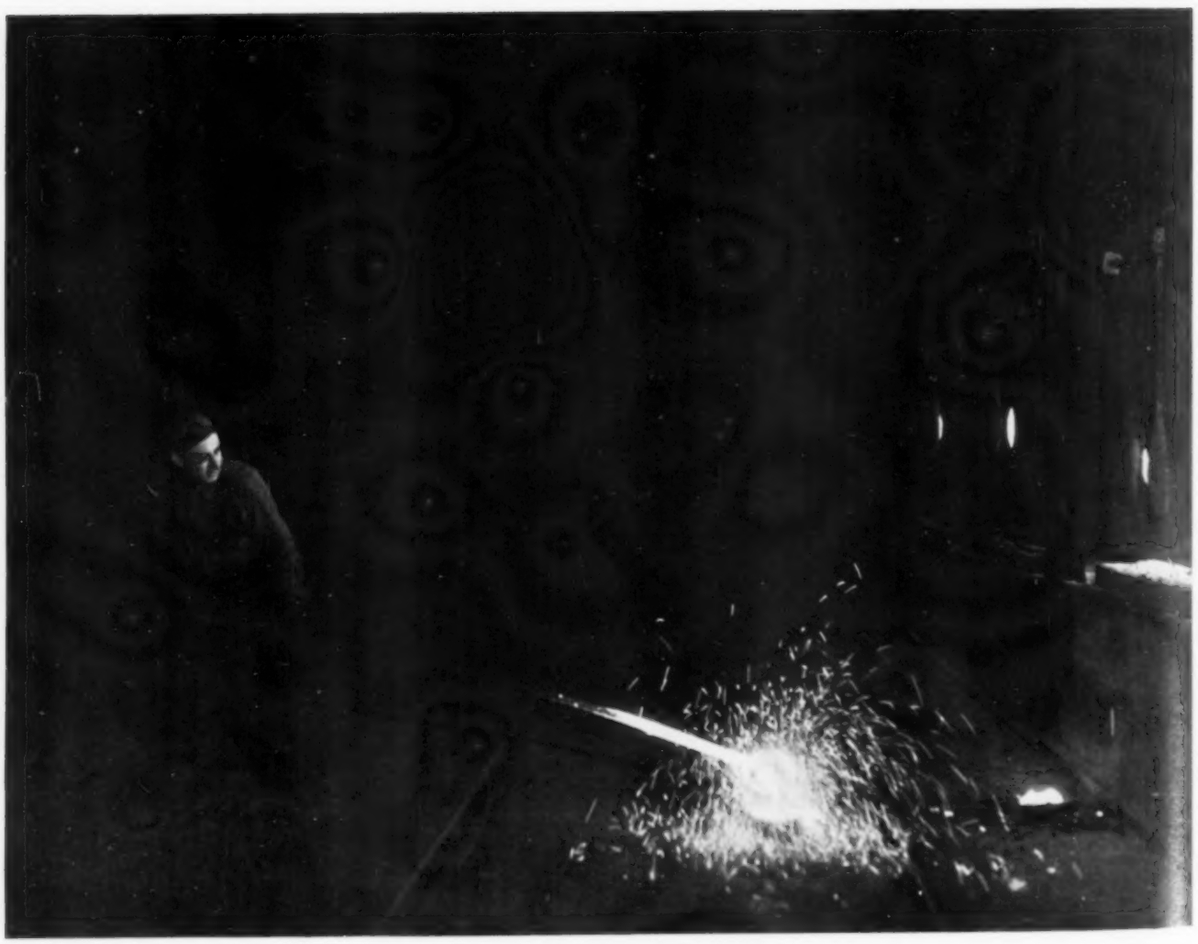
In order to check the endurance of this cast iron crankshaft against fatigue failure, a test was conducted in which a pulley was mounted in an entirely overhanging position beyond the tapered end of the crankshaft. Over the pulley passed a belt under constant tension, computed to impose a bending stress on the shaft of 10,000 lb. per sq.in. The engine was run with this load on the crankshaft for more than ten million revolutions without the slightest indication that a failure would ever occur. The significant features of this performance are that the full torque load, between the crank throw and the flywheel, was simultaneously being transmitted through the same portion of the shaft that carried the maximum bending stress due to the belt. In the second place, a fillet radius on the shaft very near to the zone of stress was designed to be only one-twentieth of the shaft diameter, but through an oversight the machinist left the junction practically square. The endurance run of ten million revolutions was completed even under these severe conditions.



Single Cylinder Gas Engine Whose Moving Parts Are High Grade Alloys — Cast Crank, Aluminum Piston and Rod, Oil Hardened Timing Gears, and Ball Bearings

Editorial

Photo Courtesy Ford Motor Co.



Open-Hearth Bill

A Test for Tool Steel

IN AN ARTICLE in the March issue Mr. Lantsberry raised the point that "body" of a tool steel has reality, even though it has not yet been measured quantitatively, and that it gives no increase in precision merely to invent another name for it, such as "timbre" or "personality." Of course, that is true, and the real reason why quality or body has not yet been evaluated is that sufficient scientific study has been lacking, and we do not know what measurable properties are chiefly responsible for reliability.

That does not mean that a method cannot be agreed upon for grading tool steels in a useful manner. Even though the system might be based on arbitrary "standards," it would form a fixed basis of reference for test data.

Such a system of classification has indeed been developed. It was described by B. F. Shepherd of Ingersoll-Rand Co. at the recent Tri-Chapter meeting in Columbus. It is based upon the time-honored criteria of the fine steel industry — namely, the depth to which a bar will harden and the fracture of the unhardened core. Neither of these observations requires any complicated equipment — only a scale and a series of comparison fractures, numbered consecutively from finest to coarsest. (In addition to the standards for fracture, the heat treatment and quenching routine should also be standardized — that is, agreed upon.) If now such observations are made on four or five samples, quenched from increasing temperatures, a good picture of the quality of the steel results, and it can be reduced to definite figures.

For instance, if the steel hardened to the proper depth, say 0.20 in., and did not harden much more deeply despite a considerably higher quench, nor did the fine-grained core (arbitrary coarseness No. 2) become much coarsened, the hardening qualities of this steel might be defined as "0.20 plus 0.05; No. 2 plus 1," where the first pair of figures represents depth of hardening and the second represents size of the macrograin. It is probable that if a second shipment of equivalent analysis hardened 0.20 and 0.25 in. deep after low and high quench, and the respective fractures were graded No. 2 and No. 3, this second shipment would be interchangeable with the first as far as susceptibility to cracking, toughness under impact, wear resistance, and the other items which go to measure satisfactory performance are concerned. Certainly these two steels would be expected to perform much differently from a third which would be graded "0.15 plus 0.10; No. 1 plus 3," notation which obviously refers to coarse-grained steel which requires a high hardening temperature to give satisfactory penetration.

It is admitted that this notation is not based on any information as to what makes the steel harden deeper or gives it a coarse fracture. But even though it is arbitrary, it is at least specific, and it is a necessary first step to determine the more fundamental facts, for it will enable different observers to be sure they are observing steels of substantially the same inherent characteristics. In this Mr. Shepherd's test will be like the measurement of micro grain size in the McQuaid-Ehn test, which has been done for many years. Both tests will enable the steel user to be more sure of the uniformity of each lot of metal — how it will act in various fabrication processes and in service — before putting expensive work upon it.

* * *

The editor of the Delaware & Hudson Railroad *Bulletin* recently overheard a lady's account of how a locomotive is made:

"You pour a lot of sand into a lot of boxes," she explained, "and you throw old stove lids and things into a furnace, and then you empty the molten stream into a hole in the sand, and everybody yells and swears. Then you let it cool and pound it, and then you put it in a thing that bores holes in it. Then you screw it together, and paint it, and put steam in it, and they take it to a drafting-room and make a blue print of it. But one thing I forgot — they have to make a boiler. One man gets inside and one man remains outside, and they pound frightfully; and they tie it to the other thing, and you ought to see it go!"

by A. J. Scheid, Jr.
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Factors affecting performance of tool steel

WITH the ever-increasing number of tool steel compositions, the publication of many technical articles pertaining to the various factors of the subject and the differences of opinion expressed as the newer ideas are advanced, the average tool steel user is becoming much confused as to just what it is all about.

As different compositions, processes and tests are developed, the immediate reaction is to try it. Frequently over-emphasis is put on the value of one particular property, while fundamentals so necessary for successful operation are lost track of. As a result compositions and processes are misapplied and tests that are not fully understood and controlled are used, resulting in considerable loss of time, money and material.

The object of this article is to point out the fundamentals involved, which must be recognized in order to develop the full possibilities of a given steel.

The factors influencing the performance of tool steels may be classified as manufacturers' variables and customers' variables. Manufacturers' variables include chemical composition, raw materials (iron and alloys), melting and casting, forging practice, and lastly annealing. Customers' variables include the selection of suitable composition, tool design, and heat treatment.

A brief description of the alloys employed today in tool steel may further your picture of alloys and their relation to tool steel.

As is well known, straight carbon tool steels depend on the iron-carbon ratio for their physical characteristics, other things being equal. As the carbon content ("temper" in old-time parlance) increases, tensile strength, hardness and cutting efficiency increase, and toughness and ductility decrease. In the adjoining table of compositions, therefore, the carbon is not shown, for it must be specified by the purchaser having in view the purpose intended. Carbon content of steels suitable for various uses is given in National Metals Handbook, 1933 Edition, p. 773.

In these carbon steels silicon and manganese are employed only as necessary deoxidizers, and not for their alloying properties.

Manganese as a tool steel alloy has its more useful field in the non-deforming steels. A composition of 0.90% carbon, 1.50% manganese is an oil hardening, non-shrinking steel of moderately high hardness, but with very low impact strength and a very narrow hardening range. Full benefit of the alloy manganese can only be obtained by its combinations with chromium and vanadium.

Chromium is the greatest hardening alloy in tool steel. As little as 0.15% chromium in a 1% carbon steel has a decided effect on both the degree and depth of hardness on quenching; a piece of 1 in. round will harden through by

water quenching from 1550° F. Higher hardness is obtained without the degree of brittleness obtained from manganese. The ability of chromium to form carbides is utilized in the high speed steels and the high carbon, high chromium steels.

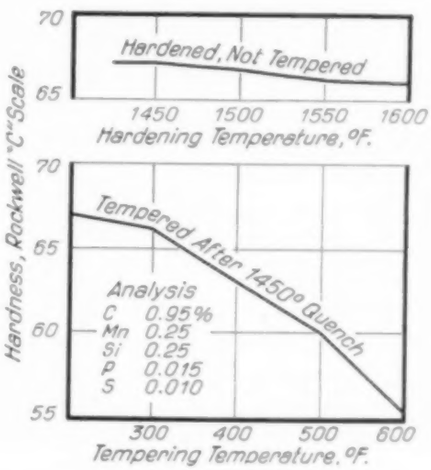
Vanadium imparts some increase in hardness, combined with considerable toughness, to water hardening steels. As little as 0.15% vanadium develops this effect. Compared with the carbon steels containing small amounts of chromium, vanadium steel is rather shallow hardening, but has an exceedingly fine grain and definite depth of case; it also renders the steel less susceptible to grain growth on overheating. Vanadium is used in high speed steels to aid in maintaining a fine structure on hardening, and adds considerable toughness to the steel.

Tungsten is little used in water hardening steels. Its principal use is in the alloy field, where it is combined with chromium or vanadium, or both. Its carbide forming ability, its stability at elevated temperatures, and its red hardness properties are further extended with the use of chromium to increase the hardness, and vanadium to increase the toughness.

Thus tungsten, chromium, vanadium and manganese are the essential alloying elements in tool steel. It is evident from the effectiveness of these alloys that their presence in carbon tool steels must be definitely controlled if uniform hardenability is to be maintained. The elements nickel, copper, titanium and aluminum may be present in carbon steels and will contribute to hardenability variations.

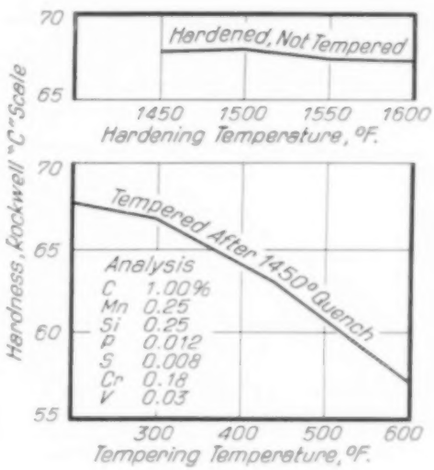
From this outline of the individual alloy properties, it can be seen that even small quantities of these alloys exert a definite effect on the resulting hardened structure of steel. Used in larger amounts and in proper combinations, the essential alloying elements form four principal types of modern tool steels, namely high speed, high carbon high chromium, non-shrinking, and shock resisting steels. There will be considerable variance in composition within each type offered for a specific purpose, and this represents the practice, opinions, experiences and development of individual organizations. In selecting a type of steel for a particular purpose, purchasers must give this thought consideration.

Turning now to the adjoining table of carbon steel tools, steel No. 1 has a wide manganese, silicon, phosphorus and sulphur specification, with no limits imposed on possible alloy



At Left Are Curves Showing Response to Heat Treatment of "Extra" Grade of Carbon Tool Steel. Small sections should be hardened from about 1450° F.; larger sections may require 1500° F. Higher heats cause grain growth, lower the impact strength, and increase danger of cracking and distortion of the tool

Below Are Similar Curves for Highest Grade of Carbon Tool Steel ("Special"), Showing Them to Have Better Hardness Values (and Working Qualities)



Chemical Composition of Typical Classes of Carbon Tool Steels

	No. 1	No. 2	No. 3	No. 4	No. 5
Manganese	0.45 max.	0.20 to 0.35	0.20 to 0.30	0.20 to 0.30	0.20 to 0.30
Silicon	0.10 to 0.40	0.15 to 0.35	0.20 to 0.30	0.20 to 0.30	0.20 to 0.30
Phosphorus (max.)	0.035	0.025	0.020	0.020	0.018
Sulphur (max.)	0.035	0.025	0.020	0.020	0.015
Chromium	No limits	0.10 max.	0.05 max.	—	0.13 to 0.20
Vanadium	No limits	—	—	0.20	0.05
Nickel	No limits	0.05 max.	nil	—	nil
Copper	No limits	0.05 max.	0.03 max.	—	nil

contamination. It is obvious that its use is limited to tools not subjected to severe conditions.

Steel No. 2 is suitable for general purposes where excessive requirements are not demanded, such as blacksmith tools and parts subjected to steady pressures. This represents the "Standard" grade of most manufacturers.

Steel No. 3 is a good, carefully controlled steel, suitable for all purposes to which plain carbon tools are adapted. It has good hardenability, and on hardening and tempering it has high shock and impact resistance. It can be used for cutters and reamers, shearing tools and shock tools. This steel is the "Extra" grade of most makers. Its response to heat treatment is indicated by the first pair of curves.

Steel No. 4 is a carefully controlled carbon steel, containing approximately 0.20% vanadium. This addition of vanadium increases the fineness of the grain on hardening, and increases the toughness. It is sometimes used in place of No. 3 or No. 5.

Steel No. 5 is the highest quality water hardening carbon tool steel. The very close element control, along with the indicated amount of chromium and vanadium, in addition to increasing the shock and impact resistance, also develops somewhat higher hardness and increased cutting values. It is used for taps, milling cutters, circular cutters, and blanking and forming dies. This is usually called the "Special" grade.

In this type of tool steel, the selection of raw materials and the melting technique are the major factors in developing the physical properties of these steels. Close control of all the elements can only be obtained by the use of carefully selected, costly raw materials.

Pure Materials Necessary

Selection of materials in developing steel for specific properties is an economic as well as a metallurgical problem. The stock available varies from Swedish wrought iron and Swedish pig iron to American iron, tool steel scrap, open-hearth scrap, and turnings on down to the baled nondescript material. A considerable choice also exists in the selection of alloys; the alloying elements may be derived from the ferro-alloys of chromium or vanadium, or from chromium ore or vanadium oxide. From this it can be seen that an innumerable number of melting combinations and conditions are possible; each must leave its mark on the product.

Melting materials affect both the "quality" of the product and the variations from one batch to another. Generally speaking, the low impurity, uniform raw material costs the most, but yields the highest physical properties and the fewest variables in the finished product.

To illustrate this consideration of physical properties, Bain and Grossmann, in their recent book on High Speed Steel, state that steels of identical composition in all elements ordinarily determined, when made from a base of wrought iron and ferro-alloys, differed surprisingly in mechanical properties from that made of scrap base. Steel made of wrought iron and alloys was reported as stiffer in hot working, and said not to anneal below 220 Brinell. In the hardened condition, its hardness was reported as better preserved at elevated temperatures, so that it had greater high speed cutting efficiency. These statements have been verified by the writer.

The manufacturing of high speed steel has the widest diversion of practice of any steel made. This is due to the wide selection of raw material available.

A high speed steel free from unreduced oxides and other impurities can only be obtained by a careful selection of melting stock and alloys. Complete refining and greater uniformity of any tool steel in the electric furnace, is best accomplished with a minimum of oxides in the original charge. This is the stage of manufacture where the variables, as seen by the hot etch test and so-called "hardenability," are either controlled or not controlled.

Casting Practice, like the selection of raw material, is an economic as well as a metallurgical problem. While low mill costs accompany the use of large ingots, metallurgical factors are better met by the more difficult casting of small ingots.

The size of the ingot cast determines the degree of segregation. As the ingot size increases, its solidification rate decreases and the dendrite growth and segregations increase. In alloy tool steels, such as high speed and high chromium steels, the slower cooling increases the danger of carbide net work and segrega-

tions. Both structures are but poorly broken up and distributed in the subsequent forging operation. In high speed steel, large carbide segregates are broken up somewhat by the forging, and lie as fragments in stringers throughout the bar. These carbides go only partially into solution during heat treating, rendering the steel more susceptible to cracking, both in hardening and under the strains of service. For this reason, the rule is that ingots should be of such size as to allow a reasonable amount of working and reduction, but no larger, in order to obtain a minimum of these undesirable casting stringers.

The degree of solidity of an ingot depends on mold and hot top design. A minimum hot top capacity of 15% by weight of the ingot is necessary to insure soundness below the crop.

As most readers are familiar with forging practice of one kind or another, they can readily visualize the care necessary during forging and rolling operations to insure a well-finished bar of tool steel. Overheating, cold working, decarburized surface (referred to as "bark"), bursts, fins, or laps can occur unless extreme care is exercised. Here, too, lies an economic as well as a metallurgical consideration. It is cheaper to reduce an ingot by rolling, yet the more difficult method of hammering insures better internal structures.

Today, good annealing practice at the mill brings the tool steel to you in a condition most suitable for machining and hardening. In annealed carbon tool steels the cementite is spheroidized. This structure has good machining properties and is in the best condition for uniform hardening. A well-spheroidized steel goes through the critical range somewhat more slowly than a lamellar structure, giving the piece a better chance to equalize its strains and lessening the tendency to warp and crack. To illustrate the reason for this, the solution of lamellar structure into austenite can be compared with soap flakes in water. The thin flakes have high solubility and disappear rapidly in the dissolving medium. Spherical particles, because they have smaller surface relative to their volume, dissolve slowly.

This outline gives you a picture of the principal phases of manufacture and the responsibility that rests with the supplier. The problem of successful ultimate product from this point on rests with the purchaser. His problem is one of selection, tool design, and heat treatment.

Tool Design

A large number of failures in hardening occur because definite, elementary laws of design are ignored. Avoid sharp corners; the use of generous fillets greatly reduces quenching strains, and even the smallest fillet makes all the difference between success and failure. Holes drilled at proper intervals in unbalanced sections will make the tool more uniform in cross-section, and will aid in preventing strain and warpage. Little recognition is given of the fact that many strains are introduced by machining. Machine marks in themselves are dangerous surface notches which should be avoided.

Before hardening an intricate piece which has been subjected to considerable machining, it is therefore good practice to normalize it. Carbon and low alloy tool steels should be thoroughly heated to 1500 to 1600° F. to put the carbides into solution and then cooled in still air.

High speed steels do not lend themselves to normalizing, on account of their air hardening ability, which tends to form a semi-hardened condition and produces flake on subsequent hardening. After forging and before hardening, these steels should be thoroughly annealed. This will relieve machining strains, lessen the tendency to warp, and leave these steels in the best condition for subsequent hardening.

Having finished a well-designed tool and passed it on to the hardening room, it will meet other variables which affect the results.

Atmosphere in the hardening furnaces is of major importance. Its control is not as simple or foolproof as some furnace people make it out to be. Improper proportion of gases results in scaling or decarburization, or both. A raw gas jet into the muffle will often give a good atmosphere; sometimes a little sawdust or coke placed on the furnace floor will help.

Successful atmosphere control depends mainly on the diligence of the furnace operator. By close observation, a set of conditions can be set up that best suits that particular furnace.

In this age of close temperature control, another factor to be watched is the ability of a furnace to heat uniformly *(Cont. on page 42)*

More comments about flakes in big forgings

Dense Steels With Low Critical Are Most Susceptible

MIDLAND, PA. — In the November issue was published an article on "Flakes in Alloy Steels" by H. H. Ashdown, to some points of which Dr. Giolitti takes exception in his letter in the February issue. We would like to state some experiences at Pittsburgh Crucible Steel Co. along the lines on which there seems to be a difference in opinion.

We agree with Mr. Ashdown as to the nature of flakes. We have always found "flakes" and "internal ruptures" or "fissures" to be identical; they form usually along the interstices of dendrites, these being the regions at which the steel can rupture most easily to relieve internal strains. When present, they are usually found in the bloom, inside an area bounded by lines drawn midway between the center and surface. This is where they would be expected, if uneven cooling were the cause.

The following is a reasonable hypothesis as to the way they form: When a bloom leaves the mill, it is at a fairly even heat throughout. If allowed to cool uncontrolled, the outside cools rapidly with the inside progressively lagging behind. Therefore, the cool outside is contracting around the hot inside. When the steel goes through the critical, a time is reached when the outside of the bloom is emerging from the transformation and is expanding while the inside is progressively entering the critical range and still contracting; the outside shell is tending to pull away from the inside and the natural consequence is a number of internal ruptures. The same effect occurs on the ends of the bloom; some metal must be cut away (about half the bloom width) before ruptures or flakes can be found in a cross section.

We agree with Mr. Ashdown in that if non-metallic inclusions are a cause of ruptures, they must be a secondary cause, because the steels most susceptible to ruptures are alloy steels made under practices to give the cleanest steels obtainable. We believe the principal conditions making steels susceptible to rupturing are first a high density, which prevents the dissipation of internal strains without rupture, and second a low critical range (due to the presence of an alloy) thus making the strains occur after the steel has cooled and lost its plasticity.

Dr. Giolitti states that he has never seen hairline cracks on the polished surfaces of gun forgings. We have found that they are readily seen when the transverse section is ground, both as dark lines and by the cooling water which comes out of the openings. If the section is heated in an oxidizing atmosphere before etching, the flake will be outlined to its full depth by decarburization. This proves their actual presence before testing strains pull them apart.

Tensile test bars being prepared from badly ruptured blooms have fallen apart in the lathe due to ruptures which extended across the bar. Though this metal had been refined by heat treatment, the fractures showed the coarse shiny crystalline structure of typical flakes.

We have not found the development of flakes to be dependent on the speed of testing nor have we been able to eliminate them by heat treatment. However, if a ruptured or flaky bloom is rolled or forged into a slightly smaller size and the cooling is controlled, no ruptures nor flakes will be found. If rolled or forged into a sufficiently small size, depending on the analysis, no controlled cooling is necessary to prevent ruptures or flakes.

In summary, if the peculiarities of various analyses of steels in various sizes are kept in mind, and the use to which each forging will be put is known, the steel maker and forgemen will be able to control the cooling conditions so that ruptures are altogether prevented or kept at a harmless minimum.

W. P. BENTER

Flakes Are True Cracks at the Krupp Works

ESSEN, GERMANY — The first thing to do in discussing the problem of flakes is to fix very clearly in the mind a precise definition for the word "flakes."

Flakes are cracks, as Ashdown states correctly, which are formed directly after forging while the forgings are cooling. It may be that some secondary cracks or enlargements of the original cracks — the true flakes — are produced when the forgings are heat treated, as by water quenching and drawing. For precision, however, metallurgical engineers when they discuss the problem of flakes, should direct their thoughts to internal cracks occurring during the cooling of forged or rolled steel.

Cracks which form during the application of sufficient stress to cold specimens of dirty and segregated steel sometimes look like true flakes, but can be distinguished by close observation. Cracks due to impurities and segregation usually present a woody structure (or, as we would say, *Faserstruktur)*, a conchoidal fracture *(muscheligen Bruch)*, or contain slag inclusions *(schlackenhaltigen Bruch)*. In large forgings it is not always easy to make a clear distinction, but it is possible.

Impurities in steel may help to develop flakes, but they are not the real cause. As Mr. Ashdown states, the purest steel can develop flakes; steel made in the basic electric arc furnace is one of the purest varieties, yet it is most susceptible to flakes.

It is not always possible to detect flakes, as Dr. Giolitti states, by careful search on the polished surface, because the cracks are often in a region under heavy compression and are therefore closed by compressive stresses. However, it is often possible to discover them after deep etching with a strong acid and repolishing.

The *development* of flakes is therefore not dependent upon the test procedure since flakes are not developed by testing. The *detection* of flakes is dependent upon the test procedure.

Furthermore, you can't cure the disease by a heat treatment, because if flakes are there, there are cracks there, which can only disappear by pressure welding and then only if air has been excluded from the cracks and the surface is not oxidized.

I am therefore in agreement with Mr. Ashdown's interpretation of the problem. My differences with Dr. Giolitti exist because the point under discussion was not clearly fixed by preliminary definition.

EDOUARD HOUDREMONT

Facts, Not Theories, About Flakes in Gun Forgings

WASHINGTON, D. C. — Mr. Ashdown's article on "Prevention of Flakes in Alloy Steel" in the November issue is considered to be reasonably accurate except as to one paragraph. Consequently when Dr. Giolitti in his letter to METAL PROGRESS in February contradicts Mr. Ashdown on five questions of fact, it might seem that since ample evidence confirms Mr. Ashdown as to these points Dr. Giolitti must be in error. However, this probably is just another case of mistaken identity.

While the same or a very similar defect had been known from early times in the higher alloyed steels (such as the material for armor and armor piercing projectiles) under the names of "chrome checks" or "hairline cracks," the word "flake" became attached to a particular defect which appeared as a disastrous plague when mass production of gun forgings

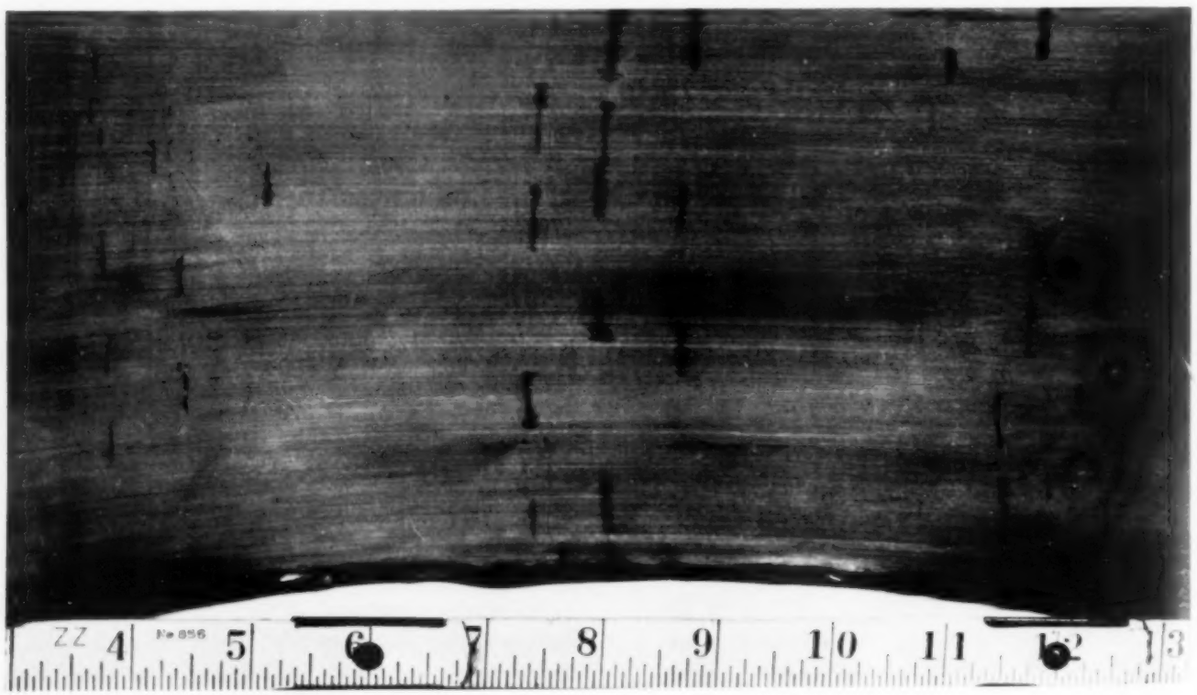
from basic electric steel was undertaken in America during the War. A type of defect of quite different case history which corresponds in some respects to Dr. Giolitti's description, has caused considerable trouble in rail steels in the track, where it becomes evident as internal transverse fissures.

Mr. Ashdown's introductory statement that "It may fairly be said that the problem was not whipped at that time as far as American forge shops were concerned, for even at the end of the War rejections of gun tubes were large" is conservative to the point of grave understatement, if confined to forgings of basic electric steel. On the other hand, flakes were not a serious problem in acid open-hearth gun steels melted in the plants of those firms with long experience in ordnance manufacture.

Of the facts, theories and statements concerning the nature, habit and prevention of flakes put forward by Mr. Ashdown and Dr. Giolitti, none had been unvoiced at that time (1917 to 1919). An additional important circumstance is that gun forgings of superior quality, made from basic electric steel, had been produced regularly in at least one plant before flake-producing practice was introduced; furthermore, production of flake-free forgings made of the more susceptible chrome-nickel steel was continued without interruption from the same melting units which produced the flaked gun forgings.

In the face of these facts and notwithstanding the urgent need for the guns, most of the basic steel gun forgings were ruined by a controllable defect! The circumstances responsible are so closely bound up with human nature that the probability of a recurrence of this or a similar disaster constitutes a menace to our national defense. It is perhaps inevitable that in the event of another war the same conditions will return and obtain.

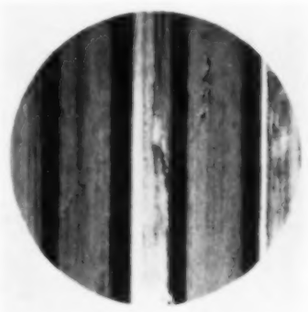
Objectors to the above statement may say that it is inconceivable that the very substantial progress made in the art of steel making in recent years should be ignored, but it was equally unreasonable that a similar course should have been followed during the War in Europe. There is no assurance that recently acquired authority will not then breed in its possessors the conviction of their competence as technical experts about metallurgical problems with which their acquaintance may be adequate neither in duration nor intimacy.



Flakes in the Bore of a Large Gun Rendered Conspicuous by Liquid Which Crept Out of These Fissures After Etching the Surface

Flakes are visible with more or less difficulty on freshly machined surfaces. Some escaped detection on guns finished, but not proved, at the end of the War. Rejections for flakes discovered subsequently in the finished bore of tubes made under War-time contracts have reduced still further the already small percentage of acceptable forgings from the plants which first attempted to make them during the War.

With the lapse of time in storage the edges of the flakes may become stained. If the bore is washed free of the grease used to prevent rusting, an oily solution oozes out of the flakes, revealing their position. If a clean bore of either an old or a newly made gun is etched and the surface cleaned of etching solution, liquid which has been in the flakes during the cleaning creeps up about the edges, thereby marking the location. One instance is illustrated in the large halftone. This method was relied upon to distinguish flakes and other fissures from surface markings before the invention of an optical instrument for examining bores at a suitable magnification.



Proof Firing, Which Throws Heavy Stresses Into Gun, Reveals Undiscovered Flakes

When flakes have escaped detection in gun tubes up to the time of proof firing, they then become visible, for the faces become separated a sensible distance, and the metal about the ends of the intersection of the flakes with the bore shows evidence of stretching, and often shows cracks running into the hitherto sound metal. The round field above shows an area in a flaked gun after proof firing.

When a gun tube, rejected for flakes, is cut up and fractured so as to lay the flakes open (the bore surface previously having been etched or heat tinted so that the faces of those flakes whose edges intersect the bore become stained), these flakes will be found on the fractured surfaces to be discolored over their whole area, while those flakes which were deeper seated have the characteristic bright surfaces. By this and by other means it may be shown that the bright spots in a fractured surface represent the exact extent of internal fissures in the forgings. Any extension of the original fissures (flakes) by mechanical strain can be noted by the contrasting character of the surrounding fractured surface. Thus, the cut on the next page shows:

(a) Zones about the three flakes which were cut into by the boring tool, darkened by oil absorbed during machining.

(b) That the outline of all the flakes is independent of the bored surface; the second flake from the left, like the others, was of circular outline but part is covered and part broken away.

(c) Unmistakable contrast between the surface of the flakes and the surface fractured mechanically for the purpose of disclosing them.

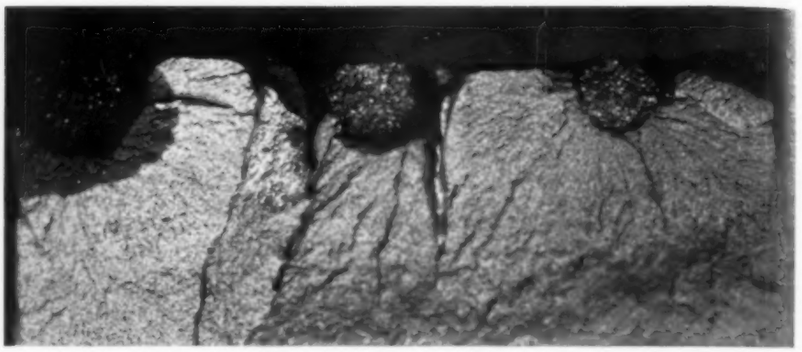
These real flakes certainly do not correspond with Dr. Giolitti's account of a defect not found in the cleanest steels, not visible in even a single instance as a hairline crack on polished surfaces, a defect produced by mechanical strain and favored by slow deformation, and lastly a defect curable by heat treatment.

The one paragraph in Mr. Ashdown's article which does not agree with conditions observed by the writer is that one containing the statement "At a forging heat they (flakes) will weld together perfectly." Not one of a considerable number of forgings reforged to smaller diameters after they were discovered to be flaked was found to be free from flakes after reforging. This has also been true of forgings upset and pierced in dies. Some of the flakes may have been eliminated but some persisted.

It is not considered desirable to add to the existing confusion of theories in regard to the origin of flakes and none will be advanced here. The following observations, based on the production of gun forgings in four years, during and just after the War, and inspection of gun forgings from various other sources up to the present time, represent definite truths and may serve to limit hypotheses. The term flakes is used herein to designate the War-time defect — internal fissures with faces of a characteristic brightness and peculiar texture, geometrically arranged with respect to the shape which the

forging has while it is cooling after forging from the original ingot.

Flakes in forgings made at one heat are substantially circular in outline and approximately flat. Except at the core of cylindrical solid forgings the flakes have a predominating preferred orientation as radial cracks on cross-sections and as longitudinal cracks in bores or in tangential sections.



Fractured Section of Bored Forging, Pierced in a Die From a Badly Flaked Blank. Oil penetrated into such flakes as reached the surface

Their orientation and shape is independent (within the limits observed in gun forgings) of the amount of reduction in forging.

Flakes do not occur within a considerable distance of the surfaces which constitute the outside and ends of the forging at the time it first cooled. Flakes may occur near one end of a forging and not at the other, or at the middle and not at the ends, or over the whole length except the extreme ends.

Flakes frequently are many times larger than any austenitic grain which may be developed in reheating the steel in which they are found. The extent of any given flake is not limited by the dimensions of any dendrite.

Attempts to produce flakes by reheating flake-free forgings have been unsuccessful. No case has been observed by the writer in which flakes were produced or diminished by heat treatment. Where treatment cracks have been opened in flaked forgings, the texture of the flake is easily distinguished from that of the rest of the fracture in which it may be found.

Flakes may be distorted by reheating and forging a flaked forging.

Susceptibility to flake bears some relation to melting practice and to ingot practice. The greatest number and greatest proportion of flaked forgings have occurred in ingots charged hot from the mold into hot forge furnaces. However, flakes have occurred to a smaller extent in ingots which have been cooled by burying in ashes immediately after stripping.

The greatest number and highest proportion of flaked forgings have occurred in the steel from basic electric furnaces operated according to a procedure designated for the production of clean steel. This metal was, as a whole, distinctly cleaner than the average product of the other types of melting furnaces used in ordnance production. However, flakes have been found in forgings from *all* of the other processes. How much responsibility is due to the type of process and how much to the method of operation is unknown.

The location of flakes with respect to the form of the forging and their circular outline, independent of the varying amounts which the ingot has been reduced at various points along its length, fix the time of formation as after forging is complete. Since they may be found as soon as the forging is cold, they must have formed at some stage of the cooling after forging. The fact that fissures are formed presupposes a condition of stress (of thermal origin) and this is confirmed by their orientation normal to the direction of principal stresses in the various forms of forgings in which they are found. That the stresses which produced the flake had been temporary is indicated by the minute distance separating the faces of the fissures after the forging has become cold. In fact the interior of the forging is usually in compression by the time the piece has become cold.

That the relief from stress afforded by the opening of an individual flake is quite local is indicated by the frequent occurrence of small flakes thickly distributed face to face at approximately even spacing around any given zone.

C. E. MARGERUM

Mr. Margerum's letter has been released for publication by the Bureau of Ordnance, U.S. Navy and the Director of Naval Intelligence. Mr. Margerum is Material Engineer, Metallurgical and Testing Division of the Washington Navy Yard.

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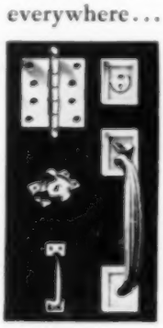

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Tool steel

(Continued from page 35) at all parts of the hearth. Even with furnaces of good construction, it may be surprising to find such great irregularities in the heat put into a group of articles spread out over the hearth. If such parts are being quenched from close to the critical temperature, look out for irregular results.

Where large numbers of standard tools are to be heat treated, definite minimums (if not maximums) of *time* as well as temperatures should be laid down for such operations as preheating, holding at the hardening heat, and tempering. To secure such data a dozen or more test pieces, the size of which would be representative of the work in hand, may be heat treated under measured times. A study of their fractures and hardness will go a long way in helping to maintain a uniform product. Each steel will have its particular temperature that gives maximum hardness with minimum grain growth, and its own characteristic response to tempering.

In hardening large single tools, like shear blades and dies, in instances where the work does not come up to temperature evenly, shut off the heat supply when the work has reached approximately 1200° F., and let the furnace and work equalize. Then proceed in the regular way.

The quenching medium is usually well understood. Where oil is required, several well-known soluble quenching oils give satisfactory results. Greater danger lies in the water quench. Waters from different parts of the country vary surprisingly as to composition of the salts and amount of gases in solution, their presence being the cause of most of the troubles of water quenching. In all cases use clean, cool water that has been boiled. Addition of one pound of salt per gallon of water makes a good brine quench; it will eliminate the danger of soft spots and, in general, give a more uniform surface hardness. Many find a 5% caustic soda (NaOH) solution a very satisfactory quenching medium.

In the handling of tool steel, bear in mind that most of the troubles are not because the facts are not known, but because we fail to take advantage of what we do know.

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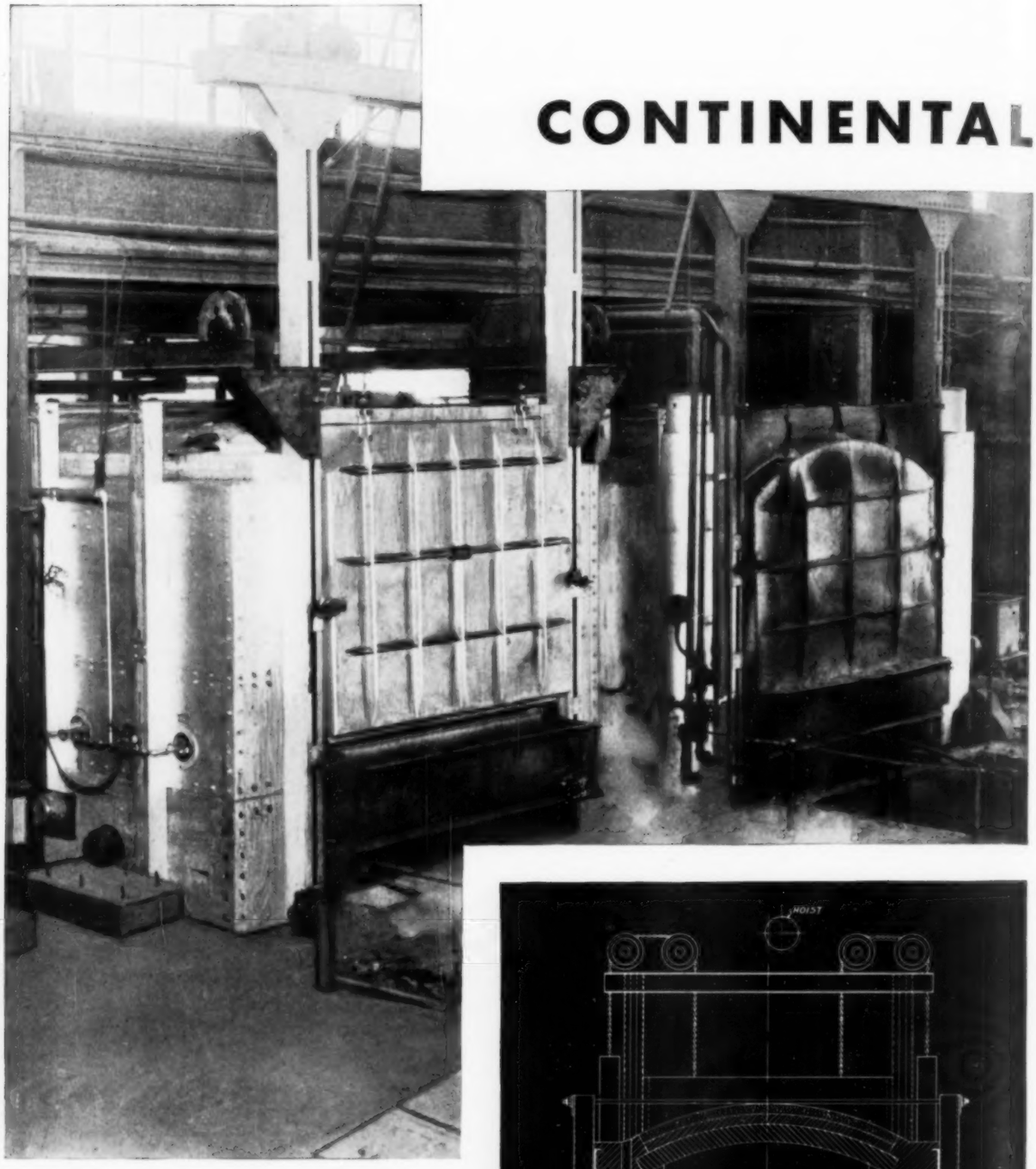

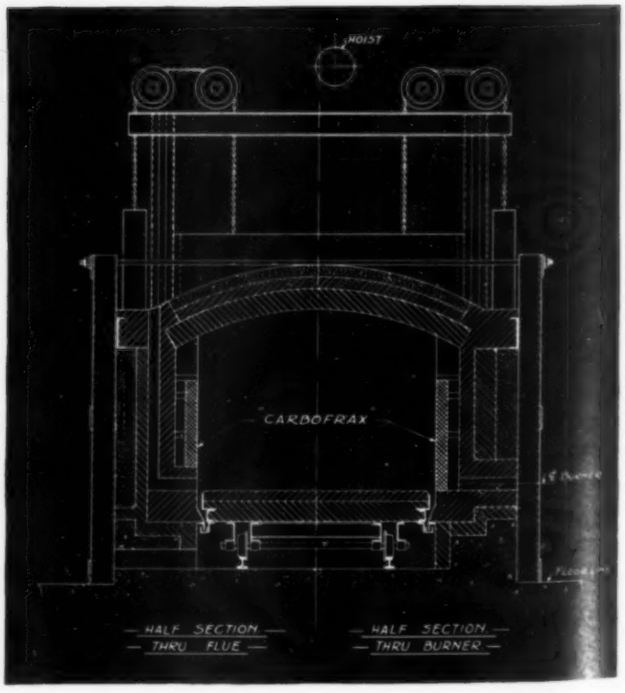

ABOVE—Two gas-fired furnaces for annealing manganese steel castings. Both are specially constructed to meet specific requirements.

AT RIGHT—Typical cross sections showing method of firing and the utilization of "Carbofrax" for its refractoriness, high thermal conductivity and durability.

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Current reading

Iron and Steel Melting

Conditions Inside a Blast Furnace, R. C. Tucker, Iron & Steel Industry, Feb., p. 165.

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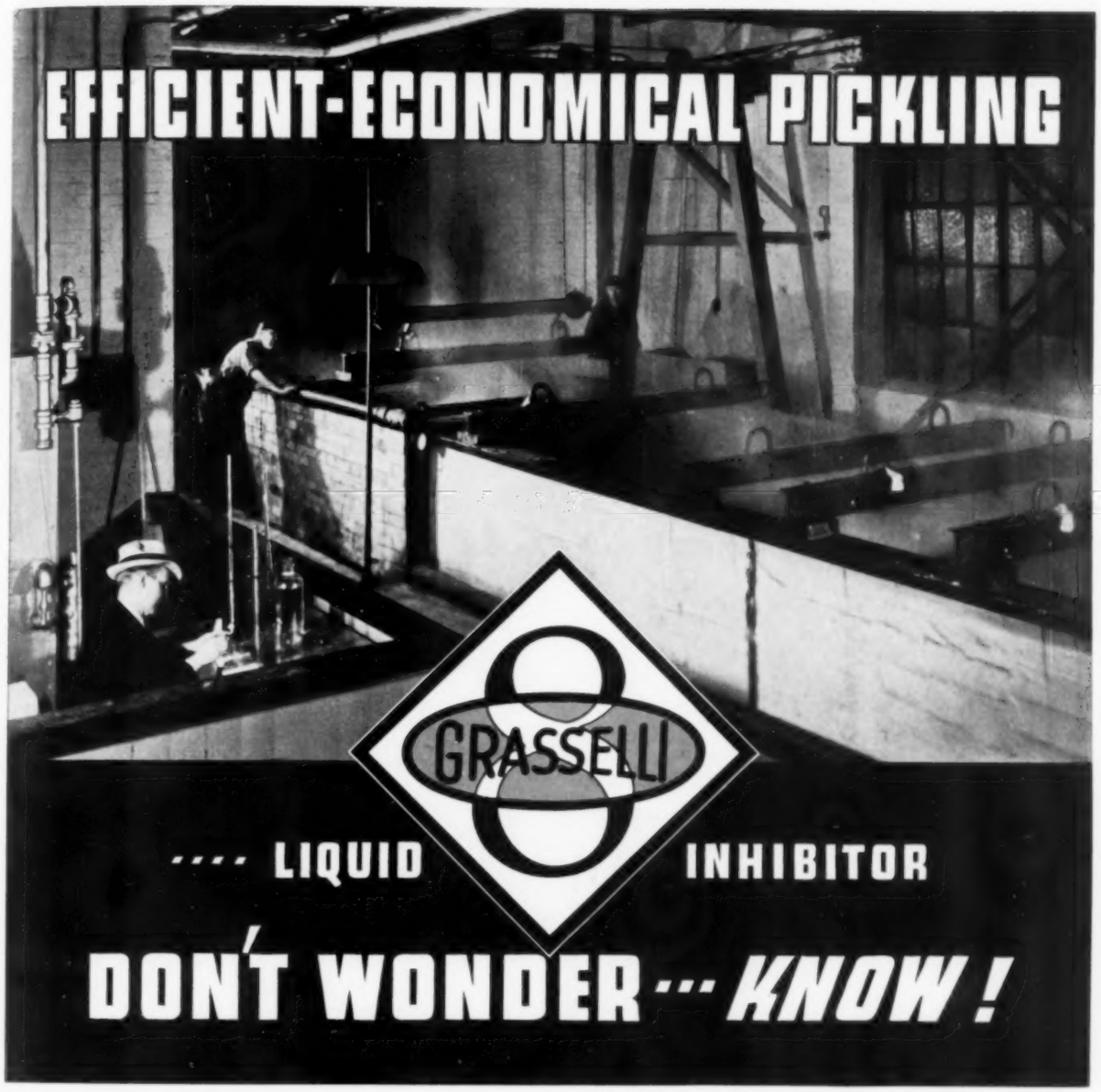

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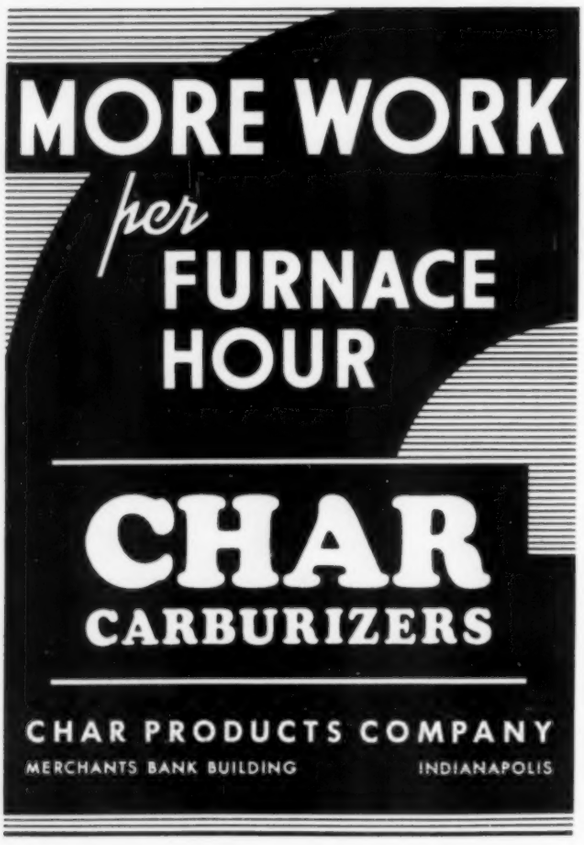

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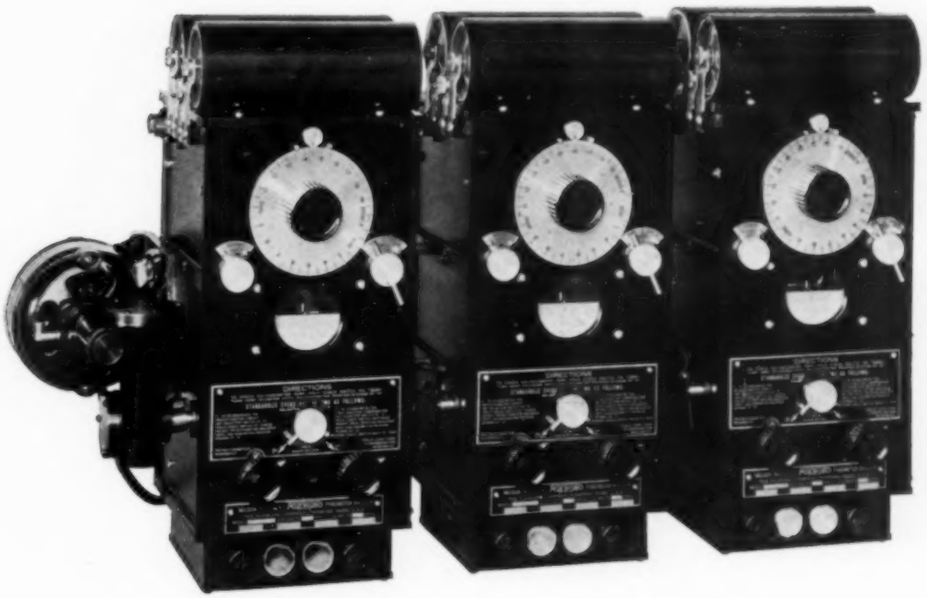

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